HOW VIDEO GAMES DRIVE THE EVOLUTION OF COMPUTING

TECHNOLOGY REVIEW

MARCH 2002

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AIDS VACCINE QUEST

Merck enters the fray with a massive new project.

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Q&A: LARRY SMARR

We talk to an Internet pioneer and director of a huge new California infotech center.

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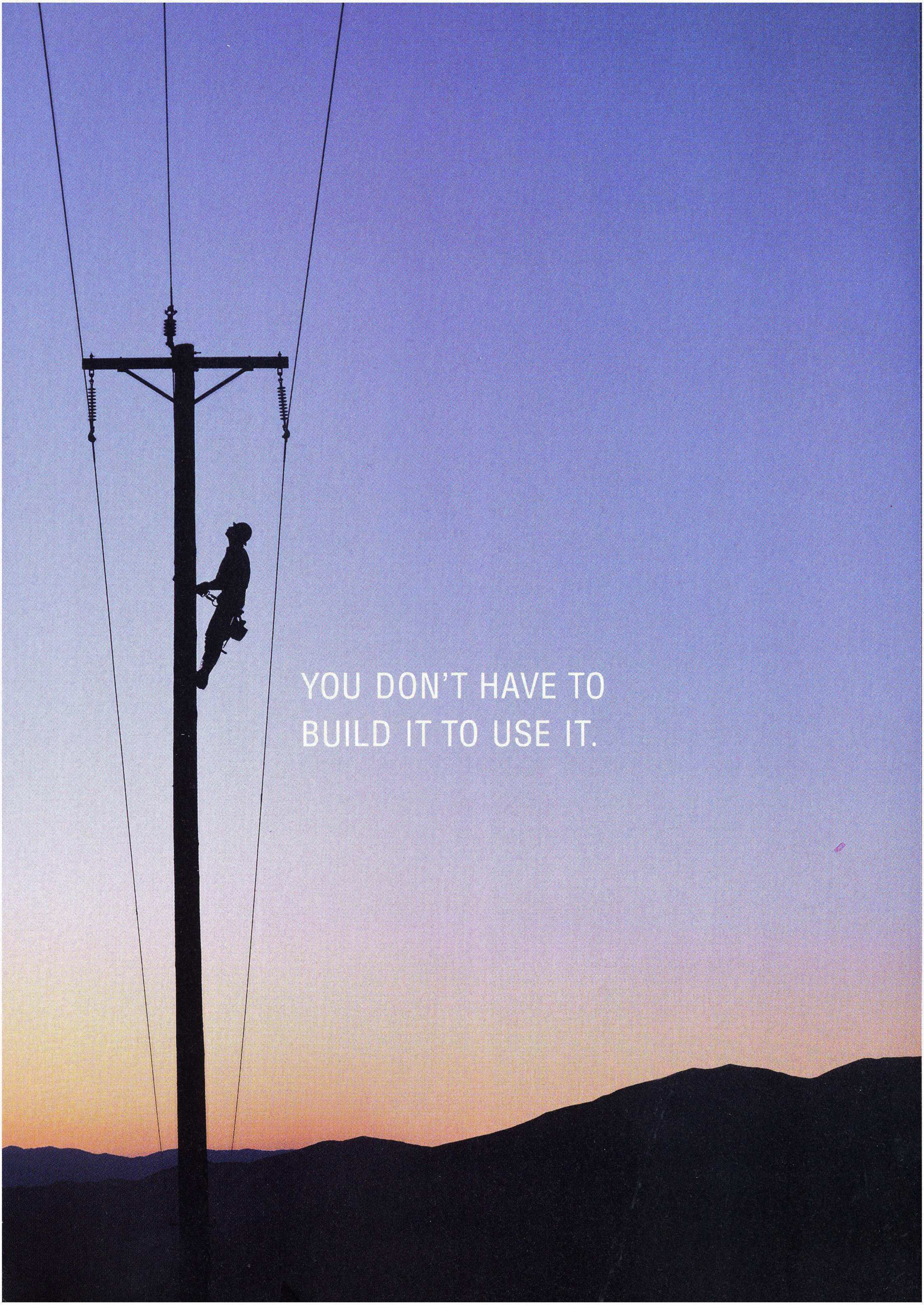
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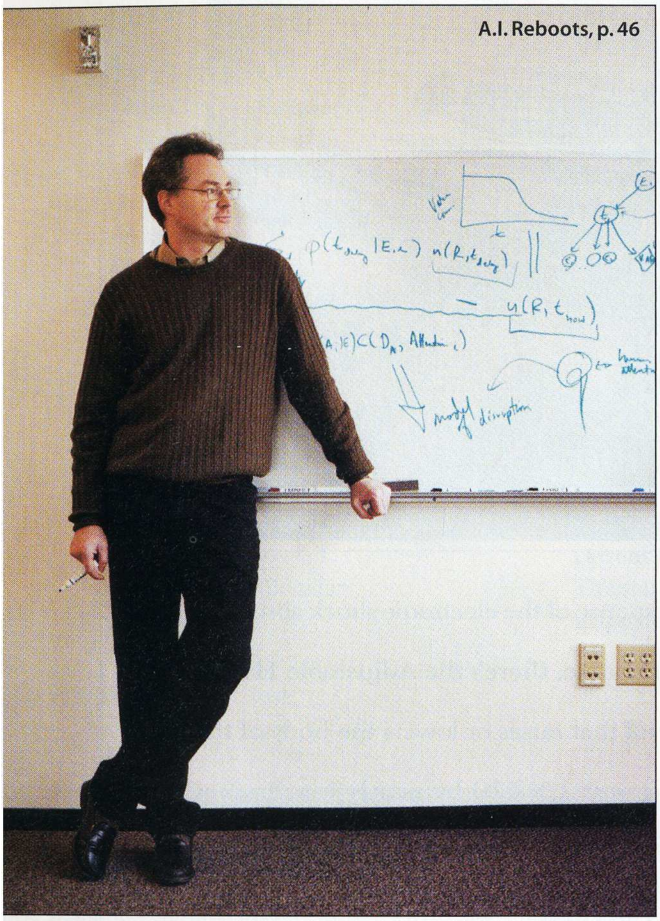

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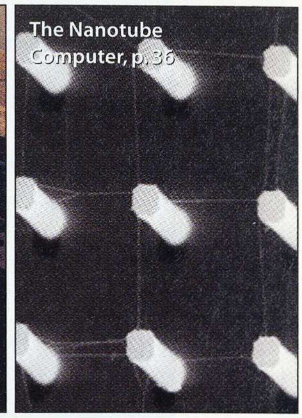

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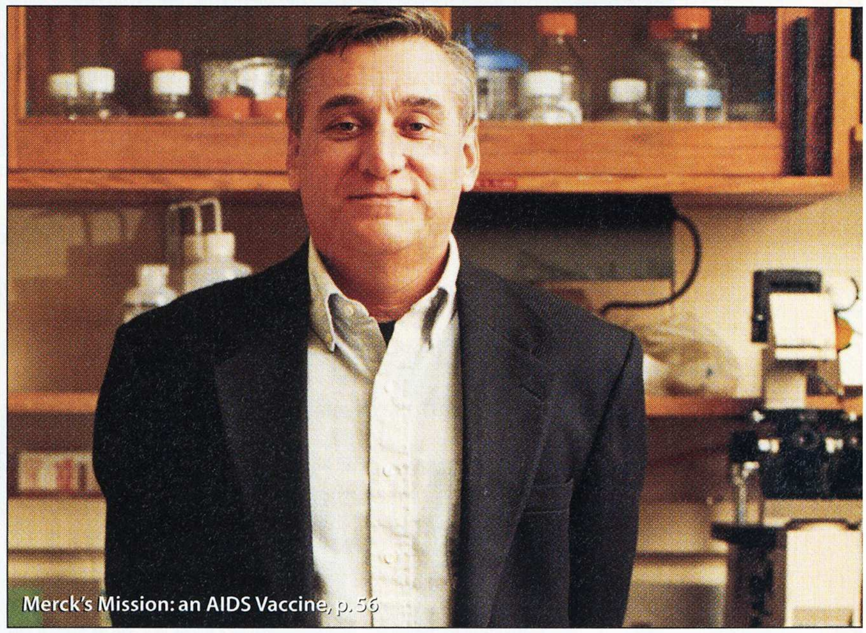

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On the cover: A single carbon nanotube growing from a silicon tip.

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T H E   L E X U S   L X 4 7 0

Progress is a curious thing. A few hundred years ago all mankind believed the Earth to be flat. Then, as the myth goes, along came Christopher Columbus. Now, something else has come along to again change the landscape of knowledge.

It is called the LX 470. And it is almost certainly one of the most luxurious and capable full-time, four-wheel-drive vehicles in the world.

But is that reason enough to rewrite history?

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Of course, there's the Adjustable Height Control that raises or lowers the body of the LX 470 by nearly four inches to achieve both the highest ground clearance and the easiest entry and exit.

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Apparently, the art of passionately pursuing perfection means that you will never mistake progress with merely moving forward.

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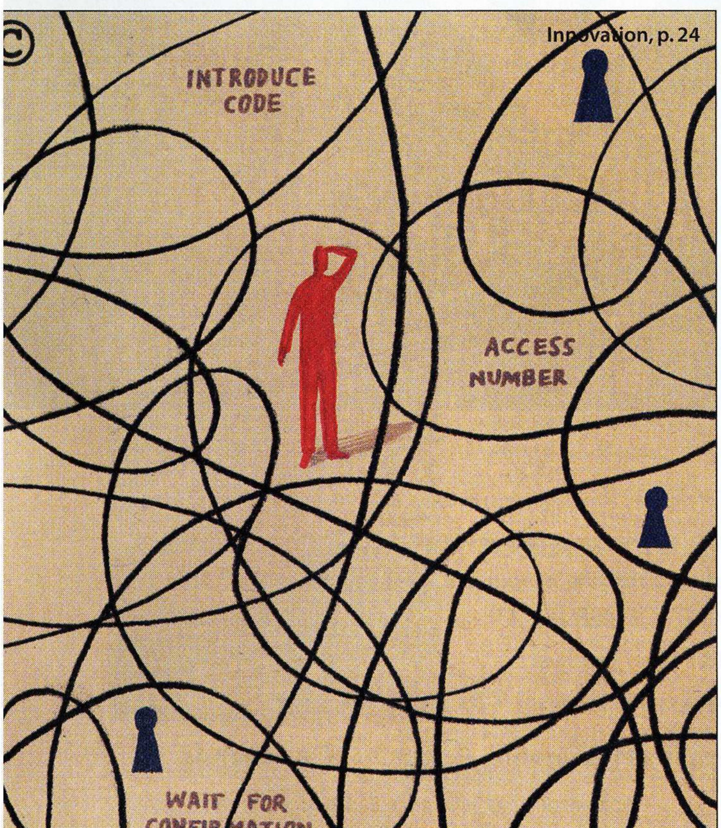

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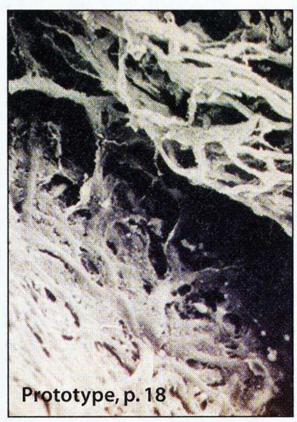
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You can't have too much of a good thing. Unless you're talking Web transactions—and your network can't handle the load. After **Nabiscoworld.com** launched, the site managers faced exactly this issue: too many visitors were arriving at the site. Which meant too many people were turned away. Unhappy. AT&T solved the problem. We re-architected the site to handle double the current monthly visits. And we added performance tracking and data-capture tools to squeeze out more usable information. Result: Nabiscoworld.com receives 90% more visits. With no change in response time. And at greatly reduced cost. It's proof that the right investment in your communications not only solves problems. It brings an immediate return. A return AT&T helps you realize.

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NANOTECH GETS REAL

In the winter of 1997, as I was assembling a team of editors and writers to relaunch *Technology Review* as "MIT's Magazine of Innovation," one application caught my eye. We had advertised in the *New York Times*, and the candidates weren't all that impressive. But one stood out. The letter and résumé had a dry, understated style combined with what looked like good knowledge of chemistry and materials science.

Now, I already knew chemistry and materials science were going to be close to the heart of the magazine we were inventing, and so I took a chance and invited the sender of the résumé, whose name happened to be David Rotman, up from New York.

I was fond of chili in those days and I met Rotman at a restaurant on Beacon Street in Brookline called Kokopelli Chili. By the time I finished lunch I knew I hadn't been wrong about the man's style. He didn't waste words, and he didn't say anything stupid. I had a feeling that he was going to be a good addition. That feeling was confirmed a couple of days later when I got the story ideas I had asked him for. Anybody who's looking for a job can say they like the idea you're pushing for your new magazine. Not many can give you a list of potential articles that flesh the concept out and make it come alive. Rotman could.

Little surprise, then, that David Rotman has turned out to be one of the stars of the new *Technology Review*. Bright, calm and unblinking. A star to steer by. And I have. In particular, I've used David's illumination to steer us through the emerging field of nanotechnology. In mid-1998, when we relaunched the magazine, not many of our readers had heard much about nanotech. Still, we believed that the manipulation of matter on the scale of atoms and molecules to make new technologies was going to be a significant part of the technology landscape.

David Rotman

When we started covering this small world, its potential was far greater than its payoff. Indeed, some of nanotech's proponents had vastly overhyped it. They were spouting fantasies about "nanobots," tiny submarines that would cruise through your bloodstream, diagnosing what ails you and fixing it at the same time.

In the face of this hype, one of the first services we provided in covering nanotech was deflating hot-air balloons. That's what Rotman did in one of our first major pieces on this field, "Will the Real Nanotech Please Stand Up?" published in the March/April issue in 1999. Rotman sorted out what was possible from things that would remain dreams for many years to come. Since then he has either edited or written just about everything we've published on nanotechnology.

A lot has changed since those first pieces. Nanotechnology has evolved from a laboratory curiosity into an object of intense interest on the part of some of the world's largest corporations. Specifically, the companies that make computer components have figured out that nanoscale, tubular structures consisting entirely of carbon atoms—"carbon nanotubes"—could lead to better, cheaper versions of three of the fundamental elements of every computer: processor, memory and display.

In four years nanotechnology has gone from laboratory curiosity to serious commercial proposition: look for nanotube-based flat-panel displays in the Christmas shopping season of 2003.

Carbon nanotubes offer a good example of how something that is basic science one year may be commercial technology the next. Nanotubes are the descendant of "buckyballs," spheres consisting of 60 carbon atoms, arranged in icosahedral form (much like the surface of a soccer ball). Buckyballs were discovered in 1985 by Richard Smalley of Rice University, an achievement for which Smalley and his collaborators received the Nobel Prize in 1996. Nanotubes were isolated in 1991.

From the first, researchers including Smalley were intrigued by the optical and electrical properties of these unusual tubular structures. Indeed, Smalley waxed enthusiastic about nanotubes in an excellent Q&A by Rotman in our pages *(TR March 2001)*. And now some of that promise is beginning to materialize. As Rotman writes in this issue's cover story, "The Nanotube Computer," on page 36, the properties of nanotubes make them well suited for replacing today's cathode-ray tubes. As early as Christmas 2003, Samsung plans to have on the market carbon-nanotube-based flat-panel displays. The first versions will probably be used in ultrathin TVs, but computer screens should follow.

The virtue of these nanotube displays is that they could eventually be much cheaper than current flat-panel screens, which are an order of magnitude more expensive than conventional displays. Beyond displays, nanotubes should move on to revolutionize processing and memory. That may not be quite as exciting as having nanoscopic submarines roaming through your blood vessels. But it has the advantage of being achievable. Following the guidance of David Rotman, *Technology Review* will continue to cover nanotechnology in almost every issue, helping you sort the possible from the imaginary, hope from hype, hot air from hot technology. TR

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EVOLVING INTERFACES

A decade of computer interface research has come up with "sort by date?" This isn't a revolution at all. In fact, as far as I can tell, none of the interfaces mentioned in Claire Tristram's article ("The Next Computer Interface," *TR* December 2001) offer me anything that I can't do today. We can already find files by textual content or date. There are plenty of picture browsers that show thumbnails of directories to make choosing and organizing graphics easier. The so-called next-generation interfaces described in your article are still limited by their physical interface—keyboard and mouse. Because the keyboard and mouse coevolved with the desktop metaphor, it's no surprise that the desktop is still the most efficient way to manage computer files. Once we develop new physical interfaces to communicate with computers, we will start to see better on-screen interfaces.

Rob Tapella
Redwood City, CA

The desktop metaphor helped make the transition from the familiar office with files and folders to the unfamiliar cyberspace. But the concepts of hyperlinks and interactive documents don't fit with the desktop metaphor, and researchers looking for new metaphors are on the wrong track. As history has taught us, the proper way to make an airplane wasn't to use a bird metaphor with flapping wings but rather to strap an engine to a barn door. Likewise, for managing life in cyberspace, we need some truly new breakthrough in thinking to create a system for organizing information and communications.

Eric Shank
Sebastopol, CA

The American consumer has grown tired of obviously self-serving pronouncements from computer scientists like those mentioned in Claire Tristram's article. The last thing we need to do is throw out the desktop metaphor, which is proven to be simple, serviceable and logical, for some untried contrivance of a sequestered academic. Better to evolve, refine and expand the existing paradigm.

Alex Cichy
San Rafael, CA

SPY GAMES

In Kevin Hogan's article "Will Spyware Work?" (*TR* December 2001), the author states that Echelon technology could monitor domestic communications, "though that is prohibited under U.S. law." But Echelon is a cooperative project of the United States, Britain, Australia, Canada and New Zealand; while it is illegal for these governments to spy on their own citizens, each country claims the right to spy on every other country. Therefore, the British and Aussies, for example, could use Echelon to spy on private communications in the United States, and then share their data with the U.S. government.

Richard Burmeister
Fairfield, IA

"The last thing we need to do is throw out the desktop metaphor, which is simple, serviceable and logical, for some untried contrivance of a sequestered academic."

TOOLS OF DESPERATION

Simson Garfinkel comes to the somewhat paranoid conclusion that the rationale behind the government's actions to curb future terrorist attacks is to limit civil liberties ("How Not to Fight Terror," *TR* December 2001). I see something very different. I see a government that is desperately choosing among a short list of existing but often inadequate technologies, such as wiretapping, to combat terrorism and calm the legitimate fears of the American public. It is incumbent upon individuals with a public forum to spark active discussion and development of new technologies that are not fraught with the overtones of infringement on civil liberties rather than criticize the desperate use of our only existing tools.

Anthony J. Dennis
Portland, OR

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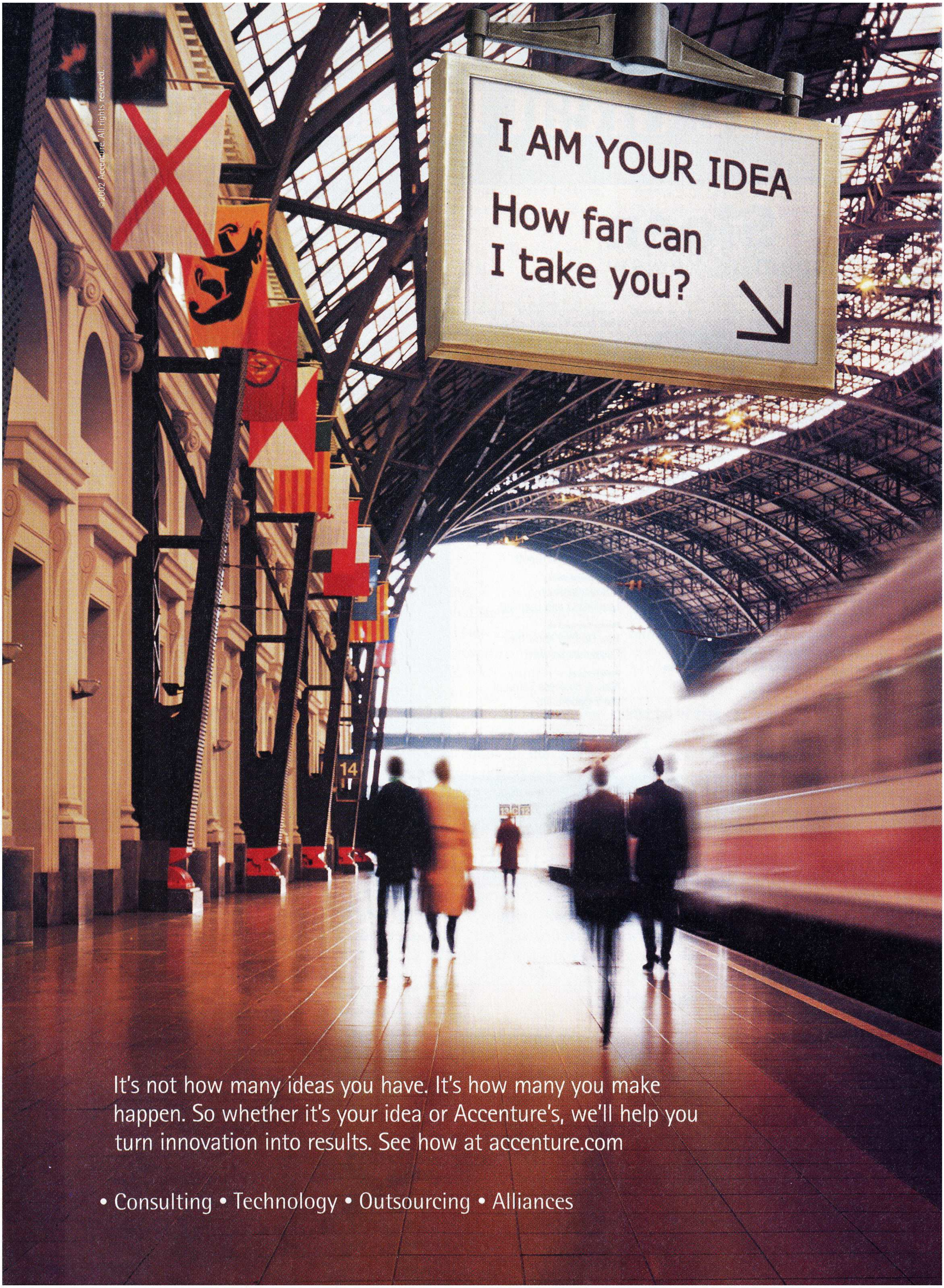
FACES IN THE CROWD

After reading Alexandra Stikeman's article "Recognizing the Enemy" in your December issue, I question the feasibility of face recognition. Do we want airport security to grab everyone whose visa has expired before boarding a plane and deport them on the spot? If you look like a famous terrorist, will your life be a living hell? Everywhere you go, cameras will call out to the cops. Remember the words of Benjamin Franklin: "They that can give up essential liberty to obtain a little temporary safety deserve neither liberty nor safety."

Steve Guenther
Tampa, FL

Correction: In David H. Freedman's article "Fuel Cells vs. the Grid" (*TR* January/February 2002), the proportion of hydrogen atoms that constitute Earth was misstated. Hydrogen is Earth's third most abundant element and accounts for about three-quarters of the mass of the universe.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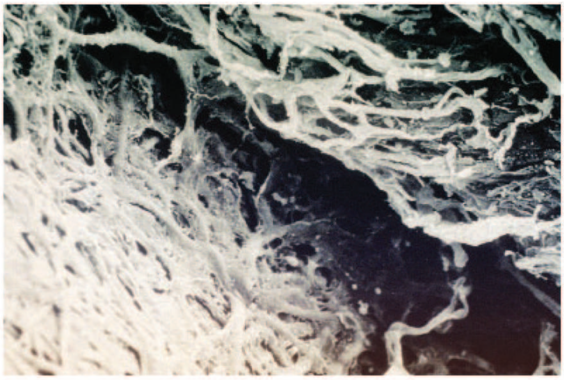
STRONG LIGHT FOR SORE EYES



Lasers treat glaucoma by unblocking these fibrous-looking drainage canals in the eye—without harming tissue.

Today's primary glaucoma treatment involves application of eye drops—as often as ten times a day—to reduce pressure in the eye caused by blocked drainage canals. But a new company called Solx, based at Boston University's Photonics Center, is developing a high-energy laser that can reduce and even eliminate reliance on daily medications for the estimated three million people with glaucoma in the United States. Solx's infrared laser emits quick pulses of light, producing acoustic shock waves in the eye that physically shake and unclog the drainage canals. "It's like beating a carpet with a tennis racket," says president and CEO Doug Adams. The lasers now used to treat some glaucoma patients emit powerful continuous beams that, as a side effect, burn tissue in the eye. Because this leaves permanent scars, patients can only undergo this procedure once or twice. The Solx treatment leaves no scars and can be performed annually. The company plans to seek regulatory approval of the treatment this spring and expects to launch the product by the end of the summer.

INFO-STRAINER

Searching a conventional database is like using chopsticks to hunt for gold nuggets in a pile of ore: every pebble must be picked up and examined individually. Engineers at StreamLogic in Los Altos Hills, CA, have invented sifting software that lets informational "ore" pass but captures the gold—alerting users to interesting new content, such as news stories on the Web.

StreamLogic's program monitors constantly changing content sources such as discussion groups, newswires and stock quotes and categorizes their information by topic, according to the frequency of certain words or word pairs. It then strains this categorized content through a mathematical filter; when content matching a preset pattern emerges, the system issues an alert or extracts the data in real time. A Web site on Middle Eastern politics, for example, could watch news feeds for stories containing the words "Arafat," "Sharon" and "intifada"—and then present only those items to the site's visitors.

UNCROSSING THE WIRELESS

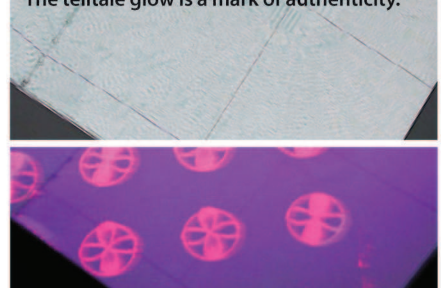
Managing communications during the chaos of war or emergency is tough enough without having to juggle a jumble of preset radio frequencies. Scientists at the U.S. Naval Research Laboratory have developed the first piece of communications hardware—called the Joint Combat Information Terminal—whose software programmability lets it interact with wireless systems past, present or future.

The unit simultaneously receives and transmits voice, data and video signals through eight channels that cover the spectrum from two to 512 megahertz. Received signals are converted to digital data that can then be retransmitted on any other frequency. Chris Herndon, who heads tactical-technology development at the lab, says civilian applications could be seen within two years for jobs such as emergency dispatching and crisis management.

INVISIBLE INK

They're the ultimate in counterfeit protection: fluorescent inks that you can't remove, copy or even see without special equipment. Made by Boston-based startup PhotoSecure, the inks can be applied to cloth, paper, metal, shrink-wrap and more. To increase security, PhotoSecure's readers not only check the color of light that the ink emits but also measure the amount of time it takes the inks to start and stop glowing. PhotoSecure hopes to market the technology to makers of products like clothing, software, pharmaceuticals, cosmetics, electronics and auto parts. Titleist, PhotoSecure's first customer, plans to use the inks to code its golf balls with information such as the identity of a club buying balls in bulk. With PhotoSecure's readers, it can then go into stores and figure out which clubs are reselling the balls at a profit.

The telltale glow is a mark of authenticity.



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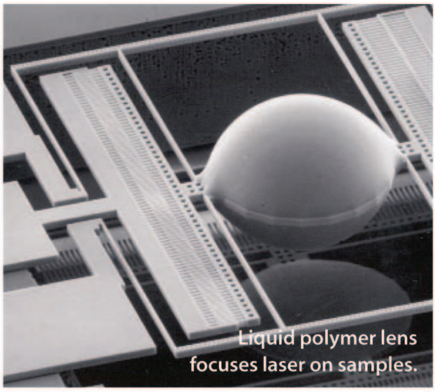


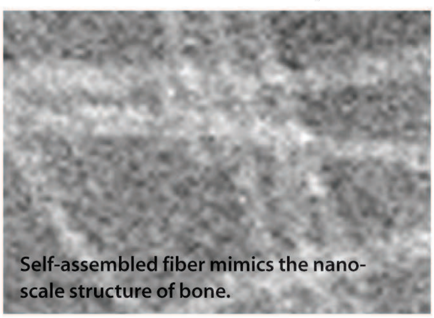
Liquid polymer lens focuses laser on samples.

The microscopes that look at tiny things, like living cells, tend to be bulky items themselves. Not so a device created by bioengineer Luke Lee at the University of California, Berkeley. In his microscope, a sample cell is dropped into a liquid-filled channel etched into a chip, where it gets tagged by a fluorescent dye and is illuminated by a tiny laser. This beam prompts the dye to glow at a specific wavelength, resulting in a sharp image of the cell. The laser's lens is a droplet of liquid polymer one-20th the diameter of a hair; it is focused by application of an electric current that changes its curvature. The microscope uses cheap components and could be fabricated the same way that microchips are made, at a cost of about $1 each. Lee believes that this microscope, funded by the U.S. Defense Advanced Research Projects Agency, will in three to five years show up in a wristwatch-sized biowarfare monitoring computer. Pharmaceutical companies could use arrays of the microscopes to study the effects of experimental drugs.

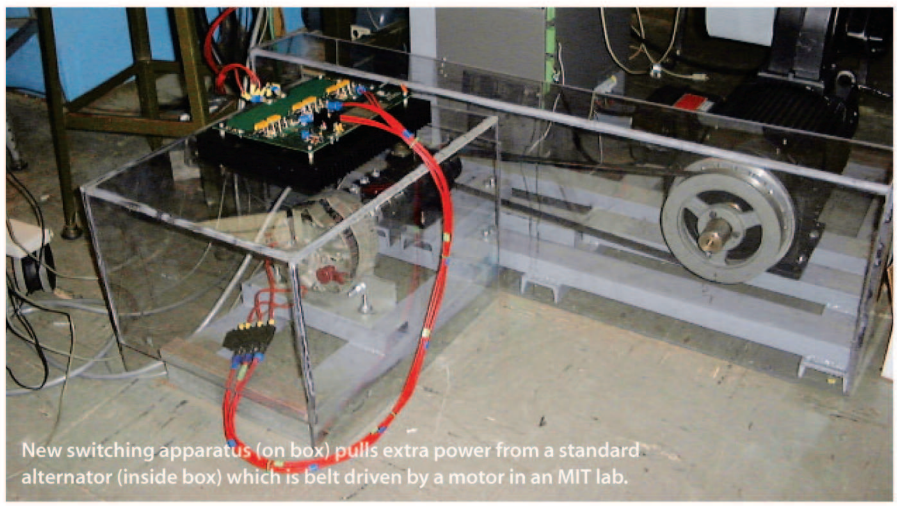
DESIGNER BONES

At Northwestern University, Samuel Stupp is growing bones in a beaker. His advance: specially designed proteins that self-assemble in water to mimic the structure of the proteins that form bones. The designer molecules assemble into tiny fibers a few micrometers long that encourage calcium compounds to form mineral crystals along their lengths.

Because self-assembly is faster and simpler than other ways to make bonelike materials, it should be less expensive. Stupp also hopes to create versions of the fibers for engineering pancreatic tissue, which could treat diabetes. Stupp's group has started experiments with the bone-promoting fibrils in animals, but he estimates that medical use of the molecules in humans is five to 10 years off.



Self-assembled fiber mimics the nanoscale structure of bone.



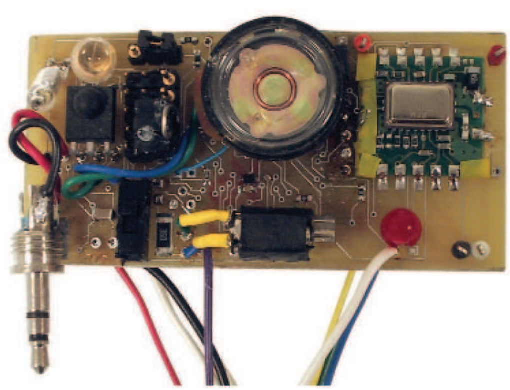
New switching apparatus (on box) pulls extra power from a standard alternator (inside box) which is belt driven by a motor in an MIT lab.

VEHICULAR VOLTMAKER

New cars will soon need 42-volt electrical systems—triple today's standard—to feed power-hungry electronics like electromechanical engine valves, exhaust treatment systems and active suspensions. MIT researchers say they have removed a key obstacle to this higher-voltage automobile by developing a mass-producible alternator that efficiently and consistently delivers 42-volt power. Starting with a conventional alternator, electrical engineering professor David Perreault added three semiconductor switches that regulate current flow. He also devised a control algorithm for those switches that enables the alternator to deliver 42-volt juice optimally at every engine speed and avoid dangerous power spikes. In recent months, Perreault's team cleared a final hurdle by making the bench-top device deliver enough power when the engine is idling. The payoff: Perreault says that three major auto-parts makers have licensed the technology for product development.

SENSITIVE PHONES

Mobile phones are an acknowledged source of annoyance in public places. Technology under development at Microsoft Research would make them more polite. Grab the ringing phone and a touch sensor signals the phone to soften its ring while you are bringing it close to your ear. If you peek at the caller ID display before deciding whether to take the call, the phone registers the action with a tilt sensor and mutes the ring. An infrared sensor detects the phone's proximity to the user. The combined information from the sensors tells the phone when it is being moved up to the ear, which allows the person to answer an incoming call without having to hit the "talk" button. Phones endowed with the sensors *(photo)* could come to market in about three years, say Microsoft researchers Kenneth Hinckley and Eric Horvitz.



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WAL-MART TRUMPS MOORE'S LAW

In terms of sheer economic impact, the single most important, dynamic, defining technological innovation in America hasn't been the silicon cliché of Moore's Law; it's the relentless promotional promise of "everyday low prices." Sure, Microsoft, Intel, Cisco and Dell may be terrific companies, but the true corporate leader driving productivity improvement over the past decade has been Wal-Mart. When it comes to managing high-impact innovation, there is no contest—Sam Walton still matters more than Bill Gates.

The reason is simple. Wal-Mart is by far the commercial world's most influential purchaser and implementer of software and systems. It is the 800-pound gorilla in a retail jungle of bonobos and howler monkeys. Microsoft and Cisco may set technical standards; Wal-Mart sets business process standards. When Wal-Mart—which is bigger than Sears, Kmart and J. C. Penney combined—wants global suppliers like Procter and Gamble or GE or Pfizer to comply with its inventory software and data networks, they do so or else. "Everyday low prices" don't come cheap.

So yes, corporate IT departments may "care" about the latest Windows upgrade or a faster microprocessor from Intel. But Wal-Mart's ongoing infrastructure innovation is what inspires their investments, actions and fears. The result has been a genuine revolution in economic productivity. This revolution also reinforces a profound truth about the economics of innovation: implementation matters far more than invention.

The numbers starkly bear this out. A recent McKinsey Global Institute report analyzing the spurt in U.S. productivity growth from 1995 to 2000 proffers provocative statistics that should give champions of "supply-side" innovation pause. "By far the most important factor in that is Wal-Mart," reports Robert Solow, the MIT Nobel Prize-winning economics professor emeritus who chaired the report's advisory committee. "That was not expected. The technology that went into what Wal-Mart did was not brand new and not especially at the technological frontiers, but when it was combined with the firm's managerial and organizational innovations, the impact was huge."

Solow's comments bear particular notice as he's notorious in technology circles for his tart-tongued observation a few years back that "Computers can be found everywhere but in the productivity statistics." In fact, the McKinsey analysis found them—but not exactly where Solow thought.

"Productivity growth accelerated after 1995 because Wal-Mart's success forced competitors to improve their operations," the report maintains. "In 1987, Wal-Mart had just nine percent market share but was 40 percent more productive than its competitors. By the mid-1990s, its share had grown to 27 percent while its productivity advantage widened to 48 percent. Competitors reacted by adopting many of Wal-Mart's innovations, including…economies of scale in warehouse logistics and purchasing, electronic data interchange and wireless bar code scanning. From 1995 to 1999, competitors increased their productivity by 28 percent, while Wal-Mart raised the bar by further increasing its own efficiency another 20 percent."

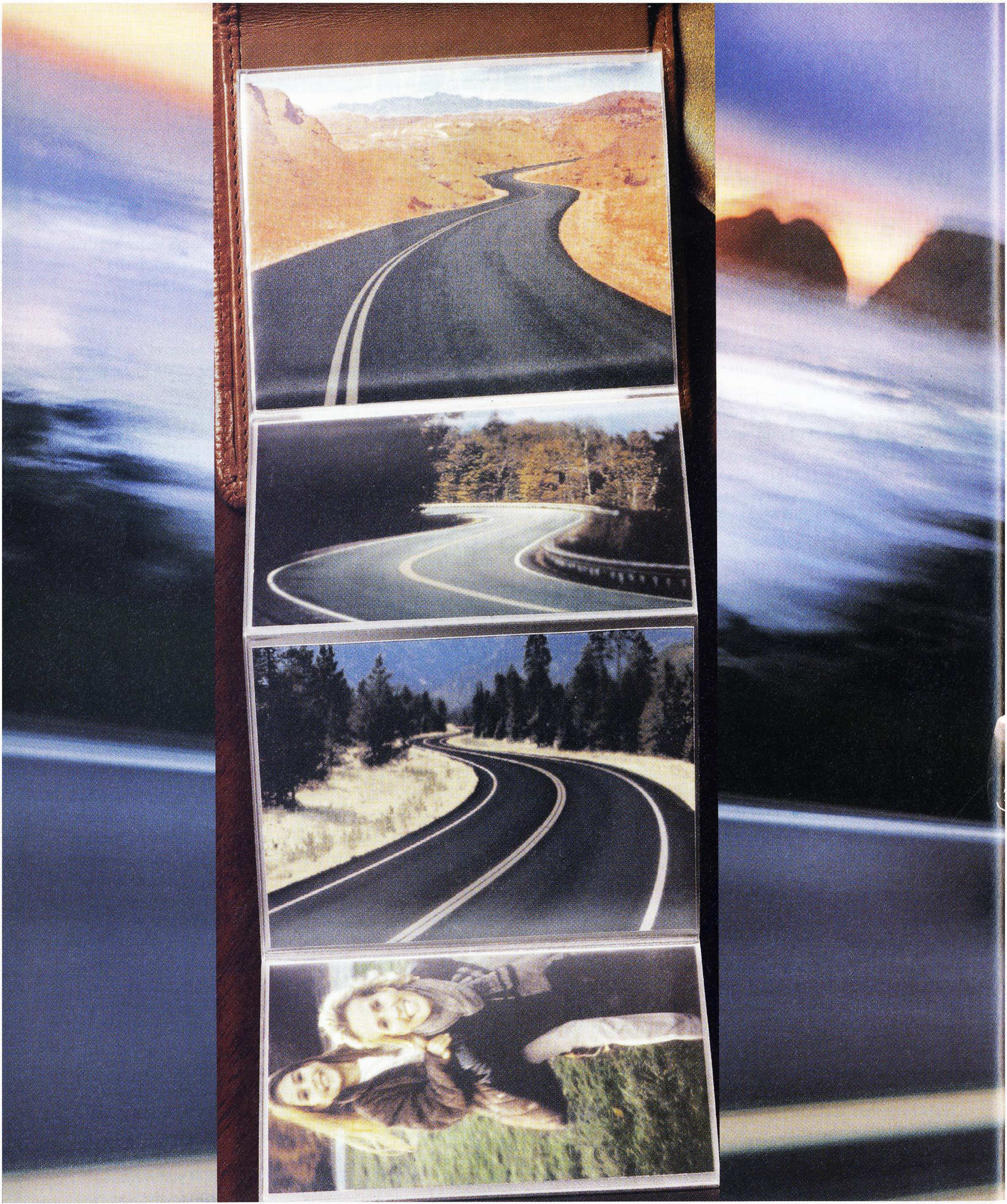
The key variables here, says Solow, are the roles of imitation, adaptation and organizational innovation that he believes traditional economists either minimize or ignore. "Our historical research emphasis focusing on measuring R&D spending as a proxy for innovation is probably a mistake," he observes. "I do think that's a gap—that we don't look enough at organizational innovation as in this Wal-Mart case."

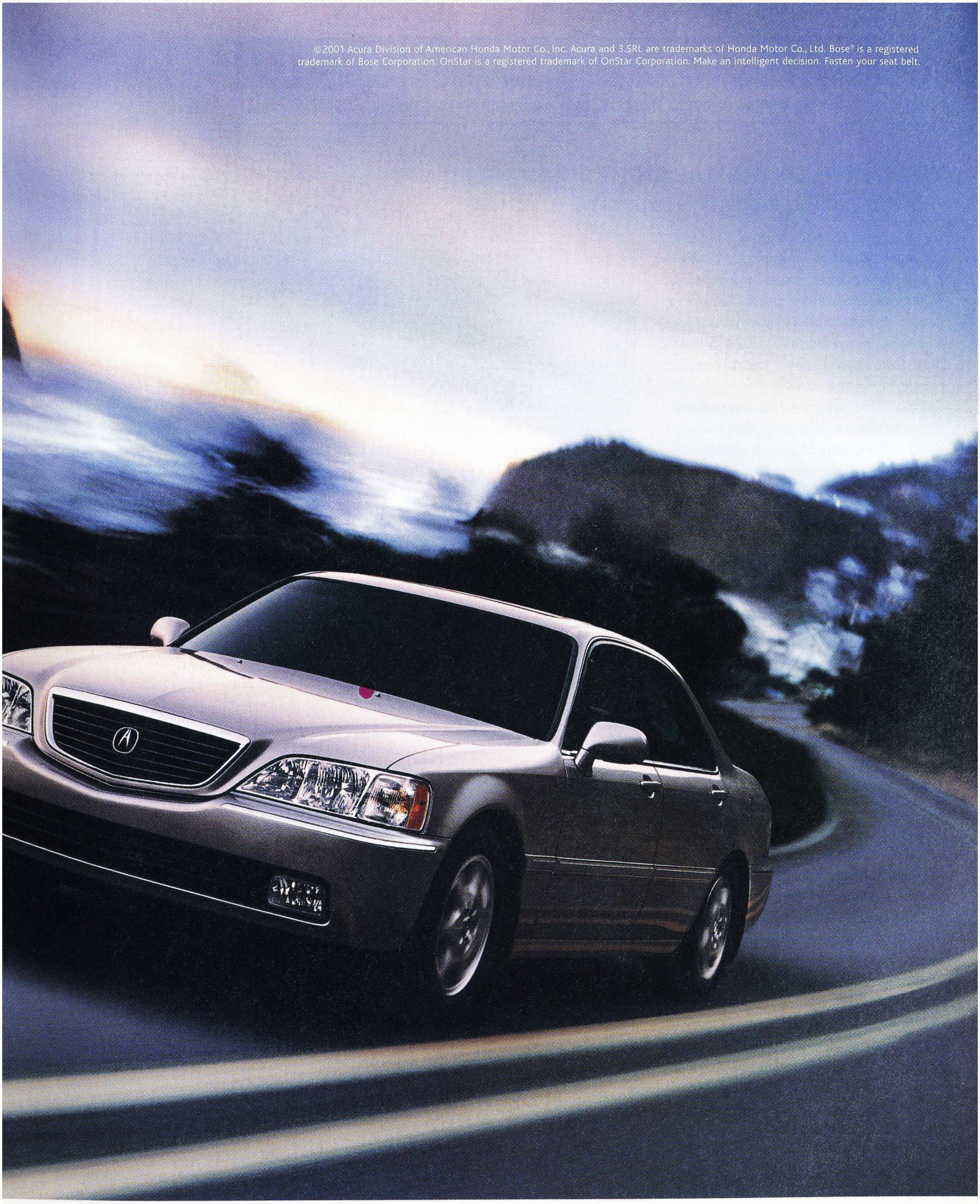
Consider Wal-Mart's $4 billion-plus investment in its "Retail Link" supply chain system. What's intriguing is not the multibillion-dollar nature of the company's IT infrastructure initiative, but the fact that it has had at least an order-of-magnitude impact on its suppliers' own supply chain innovations. That is, Wal-Mart's own $4 billion expenditure has likely influenced at least $40 billion worth of supplier investments in systems and software. Of course, those supply chain innovations are also eventually emulated by competitors, further amplifying the multiplier effect.

Wal-Mart's ongoing infrastructure innovation is what inspires investments, actions and fears. The result has been a genuine revolution in economic productivity.

This power of procurement facilitates the procurement of power. Suppose Wal-Mart decided that it would be economically advantaged by abandoning proprietary software formats in favor of "open source" to manage its supplier interactions. Imagine the ripple—or rather, tsunami—effect on the future of systems design and development in the retail, wholesale and consumer goods sectors. What happens to a Microsoft or Oracle in that environment? Suppose Wal-Mart determined that it could do a better job of offering "everyday low prices" by migrating its best customers to "smart" debit cards. Would the innovation be in the "smart card" itself? Or would it really be in the way Wal-Mart rolled it out nationwide?

Today's economic reality is that high-tech decisions made in Arkansas play a larger role in boosting America's productivity than decisions made in Silicon Valley or Seattle. If you appreciate clever innovations, spend more time with inventors, entrepreneurs and venture capitalists. If you want to know which innovations will rewrite the productivity statistics, ignore early adopters and identify the Wal-Marts in key vertical markets. Moore's Law is a necessary but not sufficient condition for economic growth; Wal-Mart's motto is what makes Moore's Law matter.

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THE DEATH OF DIGITAL RIGHTS MANAGEMENT?

A pivotal young industry is struggling to survive

It's an e-business enigma. PC owners are looking for more and more of their entertainment online, as Napster and its subscription-based successors have shown. And many of the companies that own today's most popular songs, books and movies are eager to sell their content over the Internet—if only they can find a way that's both convenient for customers and profitable for copyright owners. Yet many of the "digital rights management" companies that were founded to provide just such an online marketplace are shrinking or even disappearing from sight.

In the last eight months, a flock of content protection companies, including Buffalo, NY-based Reciprocal, San Jose, CA-based Vyou.com, Maynard, MA-based Digital Goods and Mountain View, CA-based Preview Systems, have been shut down or sold. ContentGuard, a Bethesda, MD-based Xerox spinoff *(see "Digital Rights Management,"* TR *January/February 2001),* has abandoned its content-publishing business, shrinking to a quarter of its former size in the process. InterTrust Technologies of Santa Clara, CA, the company that founded the digital rights management industry, has slashed its head count by 40 percent.

What's going on? More than just a side effect of last year's dot-com implosion, the digital-rights slump is in part a result of technological shortcomings. Content protection software is simply too obtrusive and confining to meet users' needs, say observers. "The most important predictor of success [in digital rights management] is how transparent you can be to the end user, and the industry has fared poorly on that," says Daniel Schreiber, CEO of Alchemedia, a four-year-old content protection firm based in Dallas, TX.

At the same time, many digital-rights efforts made the mistake of focusing first on fledgling consumer markets—for products like e-books—that suffer from a woeful shortage of paying customers. E-book sales have been so disappointing that the electronic-publishing divisions of several major publishers, such as Random House and Time Warner, have been closed, a fate also suffered by online e-book retailers such as Contentville and MightyWords. At ipicturebooks.com, a New York company that sells multimedia children's e-books, a title that sells 1,000 units is "a hit," according to CEO Byron Preiss. "It's very difficult to sell [digital-rights] technology to companies that are no longer trying to sell content," observes Schreiber.

In a way, it's a classic chicken-and-egg question: is the digital rights management industry hampered by a failing market, or are e-books floundering for want of better digital-rights technology? Either way, publishers, record and movie studios, and other businesses haven't given up on the idea of exploiting their valuable content via the Internet—nor are they contemplating distributing it in free or unprotected form, the way Napster once did for them.

Today's content protection tools are simply too obtrusive and confining, observers note. Many users say, "The heck with it, I'll just go and buy the paperback."

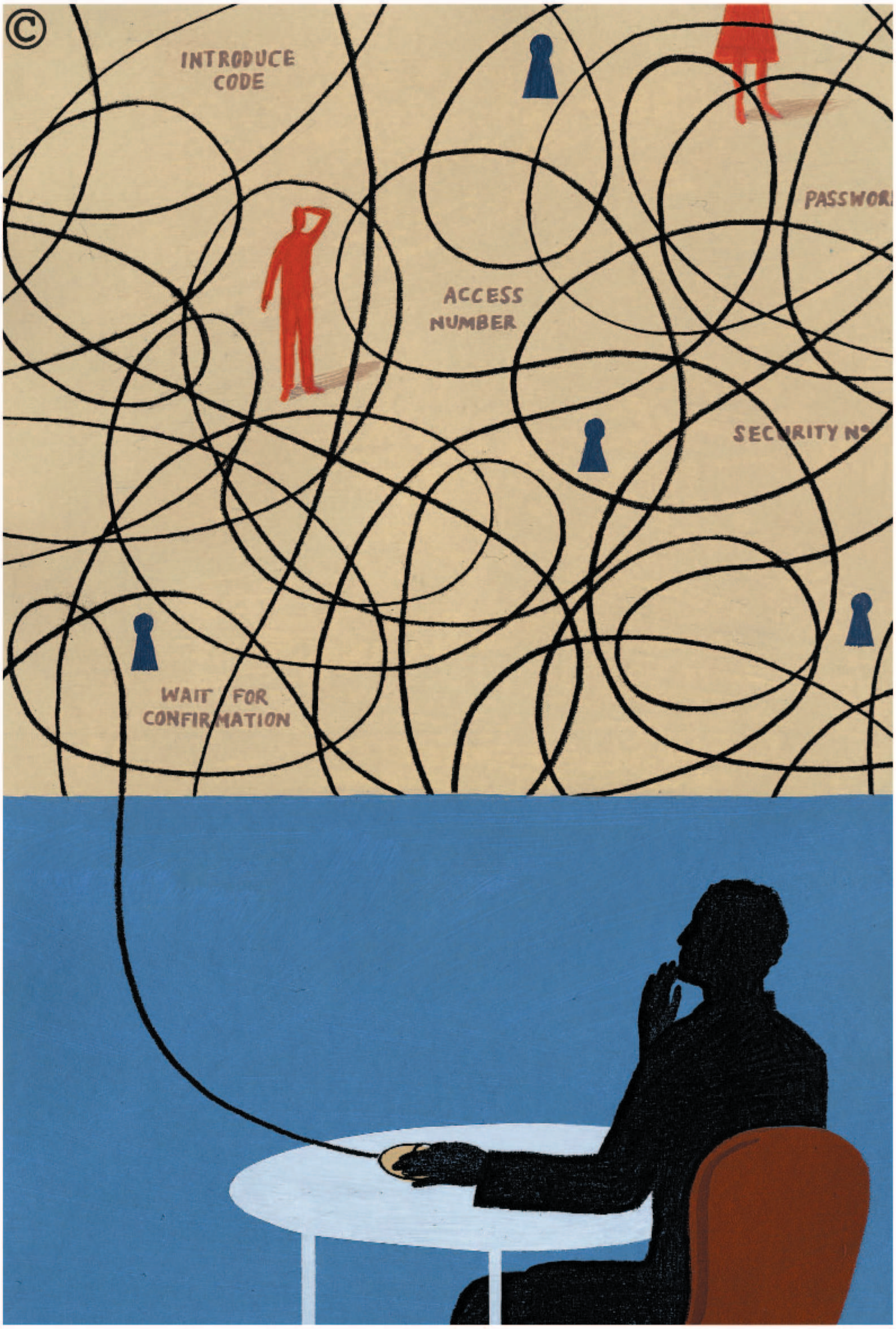
The shakeout in digital rights management firms is prompting calls for new technology that protects more kinds of content and that works more invisibly. Preiss says technological limitations "have placed this business two years behind where it should be, but that's about to change."

In theory, digital rights management software should work entirely behind the scenes, preventing unauthorized or non-paying users from viewing electronic content while giving legitimate customers the ability to read, print or share documents, depending on the rules specified by the content owner.

But if you've ever purchased a password-protected business report from a site like WetFeet.com, Hoover's Online or MightyWords—or if you were one of the nearly half-million people who downloaded Stephen King's encrypted e-book *Riding the Bullet* in March 2000—then you know that the process of obtaining a protected file can involve several disheartening steps. You may be forced to wait for a password to arrive by e-mail, for example, or you might have to download a special viewer rather than open the document in a simple Web browser (with its potentially piracy-inducing print, save and copy functions).

"The problem that digital rights management addresses is simple; the solution ought to be just as simple," says Martin Lambert, founder and director of London-based content protection firm SealedMedia. "But to actually build technology that enforces a degree of control over content without creating some horrid security framework turns out to be despicably difficult."

Another shortfall of most protection schemes is that they don't yet allow portability. In most current digital-rights systems, the coded key for decrypting a piece of content is tied to the machine on which that content was originally downloaded. This system prevents indiscriminate copying and redistribution, but it also means, for example, that you can't start reading an electronic novel on your PC then switch to your personal digital assistant when you leave the house. "It's just not a seamless experience for the user, and many of them say, 'The heck with it, I'll just go and buy the paperback,'" says Michael Letts, an editor at



AUDE VAN RYN

Seybold Seminars and Publications, a publishing-technology analysis firm in Media, PA.

Analysts say the content protection companies left standing, including Alchemedia and SealedMedia, have technologies that may break the usability barrier, finally enabling the serious online sales providers envision. "There are some extremely bright people working in this space who will be able to figure out what the consumer is willing to put up with," says Letts. Alchemedia's "Mirage" system, for example, does away with the requirement for special viewer software by making sure the decrypted form of a protected file appears only on-screen, never in random-access memory, where a computer looks for any data it's trying to print or copy. That way, publishers can put content out in a format compatible with a regular Web browser, and "the fear about the save and copy buttons is neutralized. We don't have to block those doors because the data in [memory] is still encrypted," says Schreiber.

SealedMedia's system, on the other hand, does require a special two-megabyte browser plug-in, but it stores decryption keys on a central Internet-accessible server, meaning that if you have the right password, you can access content from whatever machine you happen to be using. SealedMedia's viewer can also handle audio and video content. "SealedMedia is providing us for the first time with a robust, convenient way to deliver multimedia e-books," says ipicturebooks' Preiss.

And publishers won't be the only customers for the new breed of digital rights management. Alchemedia, for example, is targeting Mirage at companies that want to allow more collaboration across the Internet without giving away trade secrets. As Schreiber notes, "Boeing is not interested in selling their content for any price; they just want it to be confidential."

And that means computer users, whether they're ready or not, can expect to see protected content turning up in more and more corners of the Internet. "You've had one business model that has had 500 years to develop since Gutenberg's printing press, and another one that is only three or four years old," says Michael Miron, CEO of ContentGuard. "My own belief is that in five, six or seven years we will look back and see that our forecasts for the online content business were low." —*Wade Roush*

NEXT STOP: CLEAN DIESEL
Companies ready exhaust-scrubbing accessories

AUTOMOTIVE| Modern diesel engines not only provide stellar fuel economy but are quiet and peppy. Still, despite these improvements in performance, diesels remain nasty polluters. Now some of the black clouds that seem to follow diesel vehicles around could be about to disappear.

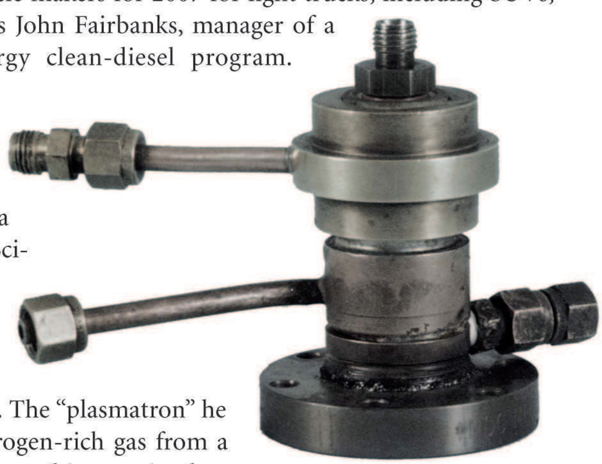
More-effective diesel-exhaust-cleaning devices are getting tantalizingly close to market. The problem is that diesel exhaust can't be cleaned with conventional catalytic converters because it contains too much oxygen, which destroys the catalysts. Enter plasmas—electrically charged gases. In a chamber attached to the exhaust pipe, rapidly pulsing electrical fields would convert oxygen molecules into ions that help trigger a first round of chemical changes in the exhaust. Then, a bit further along in the exhaust system, a catalytic converter could finish the clean-up job.

Several companies are betting such plasma devices can be installed in diesel vehicles to burn off smog-causing nitrogen oxides and unhealthy particulates by 2007. That's when new U.S. diesel emission standards will take effect; the standards require diesel engines to run as cleanly as gasoline engines. "This is a subject of intensive research worldwide right now, to become the first out of the gate to reduce diesel emissions," says Barry Bhatt, manager of plasma systems at Irvine, CA-based NoxTech.

In December, NoxTech says, the company managed a 94 percent reduction in nitrogen oxides in a laboratory engine test. NoxTech is planning to road-test scaled-up plasma systems this spring. The firm has plenty of competition, though, including a research consortium of federal labs; DaimlerChrysler, General Motors and Ford Motor; and Troy, MI-based Delphi Automotive Systems, which has partnered with French carmaker Peugeot Citroën to bring plasma treatment to market in 2005.

The plasma approach "stands a damn good chance of being the diesel exhaust technology selected by vehicle makers for 2007 for light trucks, including SUVs, pickups and minivans," says John Fairbanks, manager of a U.S. Department of Energy clean-diesel program. There's one potential roadblock, though: plasma-based exhaust treatment methods are expensive.

Still, Daniel Cohn, a physicist at MIT's Plasma Science and Fusion Center, says costs could drop under a different plasma scheme that uses a smaller chamber and a simpler power supply. The "plasmatron" he coinvented produces a hydrogen-rich gas from a diesel-fuel and air mixture; this gas is then injected into a catalyst that traps nitrogen oxides. The hydrogen gas reacts with and removes the nitrogen oxides.



A water-cooled prototype of MIT's plasmatron has fuel, air and water inlets, and outlets for hydrogen-rich gas (not visible here) and water.

Late last year, auto-parts maker ArvinMeritor, also based in Troy, MI, inked a deal with MIT to further develop the plasmatron. Whichever companies ultimately capture the market, though, the real winners are likely to be both drivers and the environment, as clean diesels roar, albeit quietly, onto the roads. *—David Talbot*

NETWORK CLOG BUSTER

BANDWIDTH| **To the chagrin of many an e-mail-happy employee, company networks operate with a finite amount of bandwidth, and too much data trying to squeeze through the network makes for sluggish performance. Santa Clara, CA-based Peribit Networks offers a solution: pump up existing capacity by culling repetitive data out of network traffic.**

The same PowerPoint presentation, for instance, e-mailed out to hundreds of sales reps, can hog bandwidth. Using algorithms originally developed to find patterns in gene sequences, Peribit's software sniffs out repetitions in network data. The software runs on a device at each end of a network link and, at the sending end, replaces repetitive data with small labels that travel on using little bandwidth. The first time the device makes a replacement it sends on both the label and the data; its partner on the receiving end uses that key to recognize the label each time it arrives and substitute in the original information. The technology works on all document types as well, from e-mails to video clips.

"The beauty of this is that it's a 'show-me' sell," says Joseph Baylock, group vice president at Stamford, CT-based consultancy Gartner. That's because the technology, which began shipping in August, produces graphical reports that show both bandwidth use reduction and return on investment—which Peribit predicts will begin within three to six months for the $20,000 box, depending on the size of the network and average monthly bandwidth costs. The system may not clear the network streets entirely, but it just might make them less crowded. *—Meg Mitchell Moore*

MARY PAT MCNALLY (PLASMATRON); JAMES YANG (ILLUSTRATION)

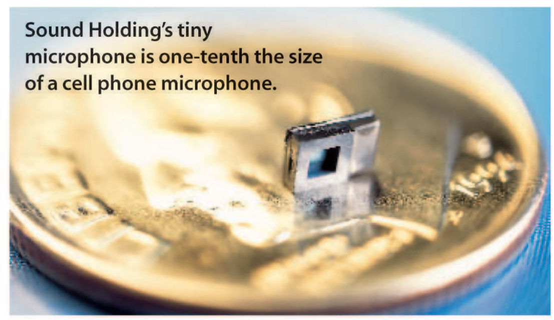
A CHIP WITH EARS

HARDWARE | Crack open a cell phone and you'll find that, while most of the circuitry has been shrunk down and integrated onto silicon chips, the microphone is still a separate device about the size of a watch battery. A Danish electronics manufacturing consortium, Sound Holding, hopes to bring microphones into the computer age, carving them from silicon using the same techniques that make today's transistors so small and precise.

Materials scientist Matthias Müllenborn and his team at Sound Holding create the sound-sensing component of the microphone by etching a rectangular hollow beneath a silicon chip's surface, leaving a 500-nanometer-thick membrane of silicon on top. Sound waves hitting the membrane cause it to vibrate, generating an electrical signal that travels to an adjacent chip for processing. The team cuts manufacturing costs by using a commercially available processing chip and gluing it side by side with the sound sensor on a bigger slice of silicon. The whole package is five cubic millimeters, one-tenth the size of a cell phone microphone.

Engineers have been working on silicon microphones for almost a decade, but manufacturing difficulties have hurt the devices' performance, preventing them from reaching the market. Sound Holding's manufacturing method should solve that problem, but observers are not sure it will be a commercial home run. "If only performance and size counts, Sound Holding's approach is good," says Robert Aigner, an electrical engineer at Munich, Germany's Infineon Technologies, which also develops silicon microphones. "The challenge will be to compete with the low prices of conventional microphones." Sound Holding is pushing ahead, though. The consortium is equipping cell phones with prototypes and plans to start commercial production in 2003.

Thanks to automated production techniques, silicon microphones should be incredibly uniform—and outperform existing microphones, Müllenborn says. Their precision could also allow for arrays of sensors capable of determining where sounds are coming from to reduce background noise in cell phone conversations. Eventually, the minute microphones could help in everything from making hearing aids more sensitive and streamlined to monitoring the sounds of aircraft engines. —*Yudhijit Bhattacharjee*



Sound Holding's tiny microphone is one-tenth the size of a cell phone microphone.

HAULING HAZARD

LOGISTICS | **Each year, approximately 300,000 items considered hazardous material—everything from batteries to fuel tanks to parts of nuclear warheads—arrive and depart through U.S. military depots worldwide. Keeping better track of them is more than just an issue of inventory control; it could be a matter of life or death.**

Which is why the U.S. Defense Logistics Agency, in conjunction with the Oak Ridge National Laboratory in Oak Ridge, TN, is developing an advanced identification, sorting and tracking system to keep more intelligent tabs on goods as they move from warehouse to destination. "Right now until a pallet arrives, there is no way to know whether there may be some dangerous stuff contained inside," says the Defense Logistics Agency's hazardous-material programs manager, John Fricke. "With this system, people will know what is coming and what they need to do to prepare for it."

Starting in the fall of 2002, whenever any shipment leaves one of the first test depots, it will pass through a special portal affixed with antennae. Any hazardous item included in that shipment will carry a radio frequency transmitter similar to a highway toll tag, which will automatically send an alert over a computer network to the shipment's destination. The alert may include anything from a basic description of the arriving item (four cases of green paint) to special handling instructions for when it gets there (store in a cool, dry place). The shipment passes through another portal at the destination, which sets off a second alert, announcing its arrival.

Oak Ridge is also developing sensors that will be incorporated into the tags to monitor temperature, humidity and the quality of the air surrounding materials such as toxic chemicals, combustible liquids and compressed gases. Sensor data could help authorities determine if an explosion or leak were imminent, for example, after a train derailed or tractor-trailer jackknifed. "Having this sort of information at hand is important if there ever was an emergency," says Oak Ridge instrumentation specialist Mark Buckner.

The system may eventually become standard among commercial, as well as military, handlers of hazardous materials. "To have an electronic audit of what went where and to whom would be a tremendous boon," says Howard Skolnik of Chicago-based Skolnik Industries, which produces drums for hazardous waste. "The paper trail of regulations there is now is mountainous." —*Kevin Hogan*

JAMES YANG (ILLUSTRATION); FURNALD/GRAY (CHIP WITH EARS)

INTERNET TO GO

High-speed mobile Net access is on its way

BROADBAND | It's a mobile webhead's dream. Instead of hooking a laptop up to a cellular modem, paying extra fees and draining cell phone minutes to download data at a snail's pace, soon it may be possible to turn that laptop on anywhere and connect to the Internet at speeds comparable to those of digital subscriber line or cable modem services, thanks to a new wireless broadband system from San Bruno, CA-based IPWireless.

Although the broadband-Internet market has fallen short of predicted demand, Peter Jarich, director of broadband research for Washington, DC-based Strategis Group, believes IPWireless's scheme is different enough from other options to succeed. "What we're talking about here is something fairly new and fairly revolutionary," he says. "People really say they would like this kind of thing. If they could move around, and if they could take it with them, there is definitely demand out there."

The system will beam broadband data from base stations to wireless modems that can plug into any device with a USB port, from laptop to personal digital assistant. IPWireless will manufacture the base stations, which wireless companies like Sprint PCS and Verizon can simply attach to their existing cell towers. Unlike existing wireless data services, IPWireless's technology is based on worldwide third-generation (3G) wireless standards—which offer both mobility and high bandwidth where other systems offer only one or the other. 3G transmissions can penetrate objects like trees and walls, and should result in fewer dropped signals for users and fewer required base stations for cellular companies.

Craig Wireless, a wireless data service provider operating in Canada and the U.S., plans to deploy IPWireless's technology in Vancouver, British Columbia, in May or June. IPWireless is also talking with undisclosed companies in the U.S. and Europe. Although pricing will be up to individual resellers, IPWireless says they should be able to deploy and sell the service at a profit without charging any more than for DSL. So far, no other broadband option—including DSL—has managed to regularly make profits while delivering service at such prices. IPWireless thinks its technology will buck that trend because users can simply plug in the $300 to $400 Palm-sized modem *(below)*—initially made only by IPWireless—and sign up online, eliminating the costly need for technicians to set up new connections on-site.

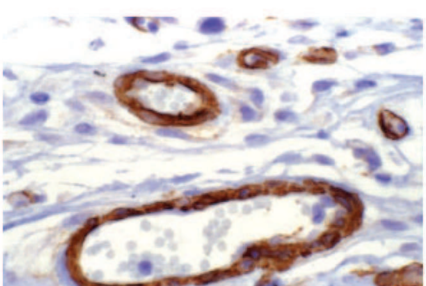
Though IPWireless is likely to be first to market, several other firms have begun trials of competing portable broadband technologies *(see table)*. If Web surfers find the technology enticing, the Internet revolution could finally be on the move. —*Erika Jonietz*

OTHER MOBILE BROADBAND FIRMS

COMPANY	LOCATION
Airvana	Chelmsford, MA
BeamReach Networks	Sunnyvale, CA
Navini Networks	Richardson, TX
Iospan Wireless	San Jose, CA

BLOOD VESSEL BOOSTER

BIOTECH | **Advances in tissue engineering augur a day when scientists can build a human kidney or heart right in the lab. But that day may still be decades away. One reason: an organ needs blood, and so far no one's engineered a complete network of blood vessels. A University of Michigan team, however, has taken an important step in that direction, harnessing the body's own resources to grow new vessels.**



A cross section of blood vessels grown in the University of Michigan's polymer material.

Most researchers have been trying to build blood vessels in much the same way they engineer organs—lining three-dimensional templates with cultured cells and growing them in incubators. But the Michigan team, led by materials scientist David Mooney, built a polymer material impregnated with growth proteins that coaxes the body to do the work. The researchers implanted the spongy material in rats, in dime-sized patches that released the proteins according to a careful schedule. The proteins—which normally play a role in tissue development—stimulated the rats' cells to migrate into the material and organize themselves into new blood vessels that were as mature as the rats' original ones.

"While we're investigating this technology in the context of engineering liver tissue and bone tissue, it may be useful in other situations as well," says Mooney. He envisions, for example, a patch that could be used to grow new vessels that restore blood flow to heart muscle damaged by a blocked artery—a condition for which about three million people annually undergo coronary bypass operations in the United States alone. MIT biomedical engineer Robert Langer sees similar potential applications in repairing damaged sections of livers or lungs. However, MIT biomedical engineer Linda Griffith cautions that the jump from lab to clinic could be tricky. "Proteins are inherently difficult to work with," she says, and the precisely timed release of growth proteins so effective in rats may be hard to replicate in people.

Though no time frame for human studies has been set, the University of Michigan has licensed the material to Cambridge, MA-based biotech firm Curis. If further experiments prove successful, researchers could be that much closer to actually growing human organs. —*David Cameron*

COURTESY OF DAVID MOONEY AND THOMAS RICHARDSON (BLOOD VESSELS); COURTESY OF IP WIRELESS (INTERNET TO GO)

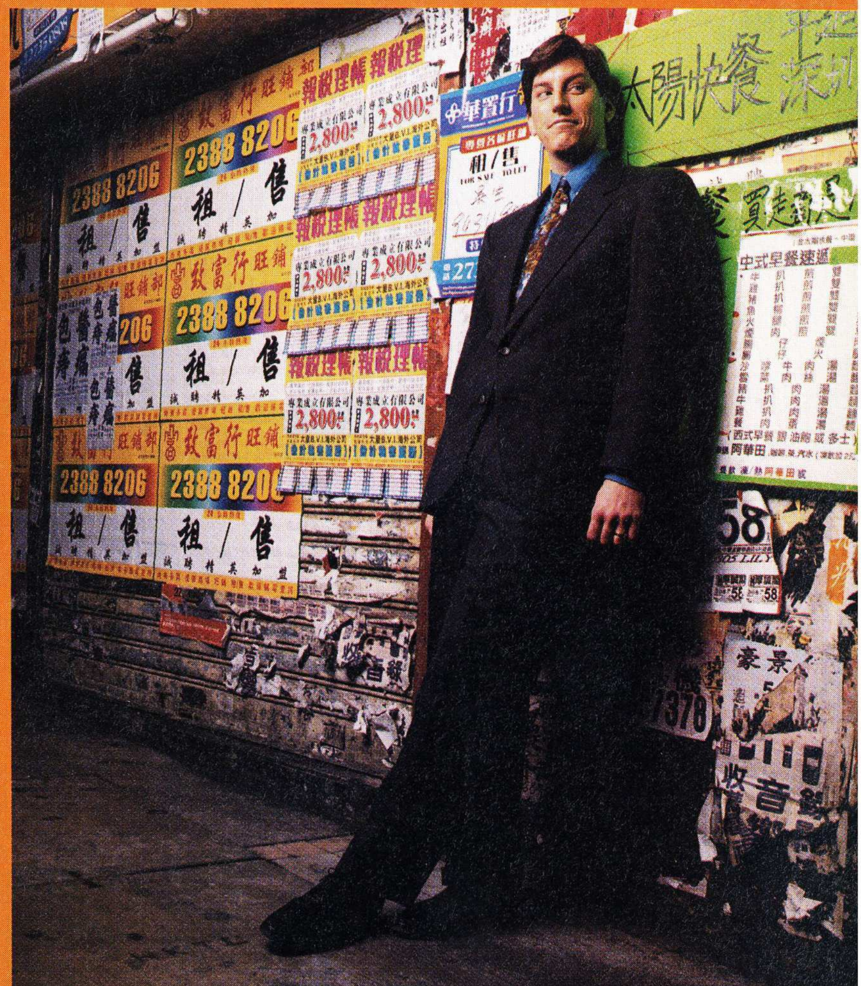
WORLDCOM

today's business thought:

they say it's the **perfect VPN** for your company.

it's the **only solution** they sell.

coincidence?



Of course not. Some VPN providers will say anything to convince you that their one existing solution meets your many existing security needs. But WorldCom takes a different approach.

We believe your business should have a solution that fits perfectly. One that adjusts as your security needs change over time. That's why we've designed adaptable VPNs that integrate seamlessly. Whether it's across our UUNET IP backbone, across our 100% dedicated, private IP backbone, or across our traditional frame, ATM and private line networks. And they work with a wide array of access speeds and types, including DSL and wireless transports. Which means you can reach your network securely from virtually anywhere, anytime.

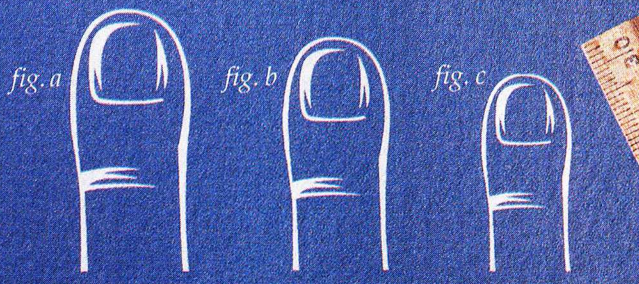
So instead of constraining your applications within the limits of your VPN, why not get a VPN with unlimited potential for your business?

Find out how to save now on secure, WorldCom IP VPN Remote Access. Visit worldcom.com/us/library for more promotion information.

generation d.

OUR CUSTOMER WANTED A BLUETOOTH MODULE THE SIZE OF HIS THUMBNAIL.

JUST OUR LUCK, HE HAD REALLY SMALL THUMBS.



Above-average human thumb. Average human thumb. Our customer's thumb.

Of course, if his hands were bigger, we never would have created the Blue Module, the world's smallest Bluetooth™ module. Nearly 60 components embedded in an excruciatingly small space. To achieve such diminutive proportions, we used advanced high-frequency design technologies to integrate the passive components and matching circuits inside the LTCC substrate. It gives Bluetooth engineers more freedom to design. And it gave our customer exactly what he needed. The Blue Module is just one of the ways we're innovating for Bluetooth. So call Murata the next time you've got a problem on your hands. No matter how small they are. For more information, visit us at www.murata.com.

Historical Figures With Small Hands

1.) Napoleon The Conqueror

2.) Tom Thumb

3.) Three Blind Mice

4.) Napoleon The Conqueror's second cousin

5.) Goliath (Surprisingly)

6.) Tyrannosaurus Rex

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Innovator in Electronics

Using LTCC technology, we're pioneering the development of ultra-small Bluetooth modules. Are you ultra-impressed?

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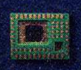


back

SYSTEMS BIOLOGY

Researchers look for a better model of diseases

Over the last few years, there's been an explosion of information in biology. The mapping of the human genome gave biologists unprecedented detail about some 30,000 to 40,000 genes. Efforts are also under way to identify the thousands—and potentially millions—of proteins encoded by those genes. Researchers are now pursuing the next logical step in integrating all this data: systems biology.

The goal is to understand not just the functions of individual genes, proteins and smaller molecules like hormones, but to learn how all of these molecules interact within, say, a cell. Biologists hope to then use this information to generate more accurate computer models that will help unravel the complexities of human physiology and the underlying mechanisms of disease. The biggest payoff: faster development of more-effective drugs. "This is really opening up a whole new world, a new way of doing things," says Aram Adourian, director of advanced technologies at Beyond Genomics, a systems biology startup in Waltham, MA.

A handful of academic groups, biotech firms and drug companies are embracing this new approach *(see table)*. Pharmaceutical maker Eli Lilly is scheduled to open its new Center for Systems Biology in Singapore this spring. The center plans to spend $140 million over the next five years to develop more effective drugs using a systems approach. In Seattle, biotech pioneer Leroy Hood has recently founded the Institute for Systems Biology *(see "Under Biology's Hood," TR September 2001)* with the objective of better understanding complex systems like the immune system, as well as diseases like cancer. Beyond Genomics is using systems biology to identify better molecular targets for heart disease drugs and is collaborating with the Dublin, Ireland-based drug company Elan to develop new Alzheimer's therapies.

Traditionally, drug researchers might identify a gene that is turned on or off in diseased patients and then develop a drug that regulates that gene or the protein it codes for. But many diseases involve a number of different genes and proteins, all interacting with each other in unique ways. Systems biology, by examining these complex interactions, could shed more light on how diseases alter cellular processes. This could help researchers hone in more efficiently on the crucial genes or proteins that cause illness, and which are therefore prime targets for new therapies. Researchers could also adjust their models to more accurately simulate the effects of a potential drug before testing it in humans, saving companies millions of dollars.

Systems biology has only recently become feasible with the development of an array of new lab tools—ranging from sophisticated protein identification methods to data-mining software—that allows researchers to process massive amounts of data. Beyond Genomics, for example, collects samples such as blood, tissue or brain fluid and then uses a number of newly developed analytical tools to identify the main genes, proteins and smaller molecules that behave differently in healthy versus diseased patients. And rather than identifying every type of molecule in a sample—"That would be a daunting task," says Adourian—the company zeroes in on only those that appear to be involved in disease.

The new data are then combined with information from public databases and fed into a computer that maps out the possible interactions between the molecules. This allows the company to spot molecules that are likely to make good targets for new drugs in a matter of weeks, as opposed to the years traditional methods might take.

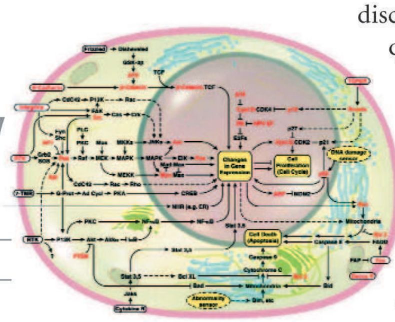
Even a single cell is an extremely complex system filled with thousands of molecules that researchers have yet to identify. And it could be more than a decade before systems biology is able to construct an accurate model of all these interacting elements in a cell. Yet as the approach evolves, and as databases on genes, proteins and other factors continue to grow, researchers will move closer to that goal—and even a partial understanding could greatly aid the drug discovery process. "I think there are quite exciting opportunities in biotechnology for companies that take on systems biology correctly," says Hood, acknowledging the technical challenges inherent in this multifaceted research.

Eventually, researchers would like to look at systems even more complex than the cell. Some day systems biology might make it possible to model an organ, like a heart, and ultimately a whole organism. Then the term "holistic healing" would take on a whole new meaning. —*Alexandra Stikeman*

THE BIG PICTURE

Companies exploiting systems biology

INSTITUTE/ COMPANY	LOCATION	FOCUS
Institute for Systems Biology	Seattle, WA	Understand human physiology and disease
Beyond Genomics	Waltham, MA	Identify new drug targets
Lilly Center for Systems Biology	Singapore	Develop new drugs
SurroMed	Mountain View, CA	Mine multiple biological data for new drug targets
Alliance for Cellular Signaling	Dallas, TX	Map all interactions between proteins in a cell



A model of a cell shows the pathways involved in cancer. Systems biology attempts to describe these complex interactions of genes and proteins.

THE INTERNET AMENITY

Before I started writing this column for *Technology Review*, I spent eight months as the "chief scientist" for an Internet startup called Broadband2Wireless. (In fact, I was the only scientist.) Our company tried to build a high-speed wireless Internet service that could be accessed in cities throughout the United States, South America, Europe and Asia. We were going to do it using unlicensed portions of the spectrum and with wireless network equipment that employed a hot new standard called 802.11. And we were going to charge no more than $50 a month.

Of course, we failed. We had $30 million in funding; we needed $200 million. We had a handful of good engineers; we needed dozens. Nevertheless, our company's basic vision was right on target. We knew that one day there would be a pervasive wireless Internet that's as easy to use as today's telephone network. Within 10 or 15 years' time, practically every computer and every handheld device will be online all the time.

What many people don't realize, however, is that this visionary network is increasingly up and running today. And it doesn't even require any new technology, business models or significant investment. Indeed, if there is a single difference between the Broadband2Wireless mission and the reality of this new ubiquitous network, it's that the real wireless Internet doesn't cost $50 a month—it's free. All that's required, really, is openness.

One of the most surprising things we learned from launching our Internet startup was that providing wireless Internet service is really cheap. What ended up bankrupting the company were all the ancillary services we had to develop—credit card billing, technical support, the corporate Web site and the various security measures we had to put in place to prevent unauthorized use of the network by nonsubscribers. Organizations that aren't trying to make money providing wireless Internet service can do away with all of these measures and offer the service for free.

This isn't just some techno-utopian notion—it's today's reality. Of course, there's not much incentive to set up towers and deliver free wireless broadband to homes that can't get high-speed Net access through cable modems or digital subscriber lines. But many businesses and universities are doing their part right now by making wireless Internet service available without restriction in their buildings and nearby public areas.

The other day, for example, I was at the Boston University school of journalism to have lunch with a friend, but he wasn't there. Realizing that I was half an hour early, I took out my laptop and discovered that I was getting an excellent signal from the school's wireless network. But I didn't just get a signal—the university's network helpfully gave my laptop an address on the Internet. Within moments I was downloading my e-mail and surfing the Web. When I shut down my computer 30 minutes later, the address was automatically returned to the university. And since the J-school's network wasn't running at full capacity at the time, even my minor use of bandwidth had no impact on other users. Total cost to Boston University: zero. (The same thing happened a

BRIAN CAIRNS

few weeks later when I was at Harvard's John F. Kennedy School of Government.)

Sadly, however, not every wireless network is open. A few of the schools and businesses that I have visited have set up blocks to lock out "unauthorized" wireless cards—much as we tried to do at my wireless startup. Fortunately, more organizations are realizing that its easier, friendlier and ultimately cheaper to have a network that's open to employees and visitors alike.

Essentially, the schools were providing me with wireless "IP tone," the 21st-century equivalent of telephone dial tone. (IP stands for Internet Protocol.) Bring your own hardware and a wireless local-area network card, and you can get on the Internet for free.

It's free for the schools, too. Well, almost free. Assuming an organization already has a high-speed Internet connection and has spent $100 for a wireless transmitter, the only real cost associated with providing this service is the negligible amount of Internet bandwidth used by guests like me. Since most organizations pay flat fees for their bandwidth, there is no marginal increase associated with opening their networks to visitors. The same principle applies to campus phones that let anyone dial an off-campus toll-free number.

Of course, allowing strangers to tap into an organization's network does carry some security risks. Were a visitor to use his or her laptop to attack computers at the CIA or send out a million unsolicited e-mail messages, the university's largesse could quickly require an expensive and time-consuming investigation and cleanup. But the increase in risk associated with having an open network is minuscule and, ultimately, irrelevant. Telephones in lobbies are so useful that most companies are willing to live with the risk that someone could use them to commission drug deals or call in threats to the White House. With the Internet as large as it is today, trying to increase security by restricting physical access is a losing proposition. Besides, if bad guys are actually in your building, keeping them off your wireless network is probably the least of your worries.

Other organizations are experimenting with a cut-down version of IP tone that I call "Web tone"; basically, they provide a computer with a Web browser and a high-speed connection, but they don't let visitors plug in their own equipment. Amtrak, for example, offers Web tone in its Acela lounges in Boston, New York, Philadelphia and Washington, DC. "You can access any e-mail account—MSN, Yahoo!, whatever your flavor," says Michael Toczylowski, Amtrak's manager of station technical support.

But the problem with Web tone is that it limits you to only those services that are available through the Web. While America Online, MSN and Yahoo! all offer Web-based e-mail, most corporations don't. Public Web browsers aren't particularly valuable to me because they don't allow me to download my e-mail to my laptop and then read it later on the train. If Amtrak provided IP tone, I could.

What makes IP tone possible is a broad collection of standards. Because I'm writing about wireless networks, it's tempting to focus on 802.11(b)—the standard that makes it possible to network computers over the air. But far more important for the emergence of ubiquitous wireless connectivity are the standards that make the Internet plug-and-play. The most important of these standards is the Dynamic Host Configuration Protocol, which is what my laptop used to get a temporary "lease" on an Internet address, as well as the other information necessary to send data over the wire. For years the support for this protocol has been a largely dormant part of the Macintosh, Windows and Unix operating systems. Now it's actually being used, thanks to those little "home routers" that let people share a single high-speed Net connection among several computers in their households. As a result, when I was at a friend's house in San Jose, CA, a few months ago, all I had to do to get a high-speed connection for my laptop was plug it into the wall. Everything else was automatic.

One of the most surprising things we learned from launching our Internet startup was that providing wireless Net service is really cheap. In fact, it's essentially free. All that's needed is openness.

With a $50-per-month Internet connection and either a $70 router or a $150 wireless base station, any home or business can provide high-quality IP tone. The base station makes it possible for people to use this IP tone without stringing up any cables, which is nice—but it's the connectivity that's the important thing.

A growing number of hotels and other businesses catering to business travelers are trying to sell IP tone (Wayport and MobileStar are two of the better-known players in this industry). Most provide Ethernet jacks in the rooms; some provide wireless service. A friend of mine travels with his own wireless hub, so he can turn any hotel's Ethernet jack *into* a wireless service. To me that seems excessive, but he likes the freedom of being able to take his laptop anywhere in the room, or out on the balcony.

Ultimately, IP tone becomes valuable not when it is just in your hotel room but when you can count on it being everywhere. I have it in my house for guests. My friends have it in their offices. This is the friendly future that I see starting to shape up: instead of seeing Internet connectivity as a profit center, my guess is that businesses, universities and government facilities are going to provide IP tone to visitors for the same reason that they offer free local telephone service, water and the use of rest rooms—it makes the environment warmer, friendlier and more productive.

Do your part: set up an open network today.

The ABC's of Safety: Air bags. Buckle up. Children in back. *At maximum output.

ENGINEERED TO BE ALMOST PSYCHIC.

Introducing a car so technologically advanced, it can sense trouble and begin to adjust for it before the driver even notices that there's a problem. It's the 6-cylinder 212-horsepower Outback VDC from Subaru. The VDC stands for Vehicle Dynamics Control, a highly intelligent stability system that rivals those found in vehicles costing thousands more.

Using a sophisticated series of sensors, VDC can help prevent loss of control due to oversteer, understeer, wheel spin or vehicle drift. The instant a difference is detected between the driver's intended direction of travel and the path the car is actually taking, VDC takes corrective action. Momentary brake pressure may be applied to individual wheels. The All-Wheel Drive system may redistribute the amount of power between the wheels. Even the engine's output may be momentarily reduced. Before the driver even realizes that loss of control is impending, any or all of these measures may be applied automatically to help restore directional stability. It's almost as if the car has a sixth sense.

In fact, in every sense the Outback VDC is a remarkable vehicle. It even features a state-of-the-art 200-watt* sound system built exclusively for Subaru by McIntosh®. With 11 speakers placed in 7 strategic locations, the audio quality has been specifically tuned to the car's unique acoustics.

The Outback VDC from Subaru. Truly a phenomenon in the world of automotive engineering. To find out more, visit us at **www.subaru.com**.

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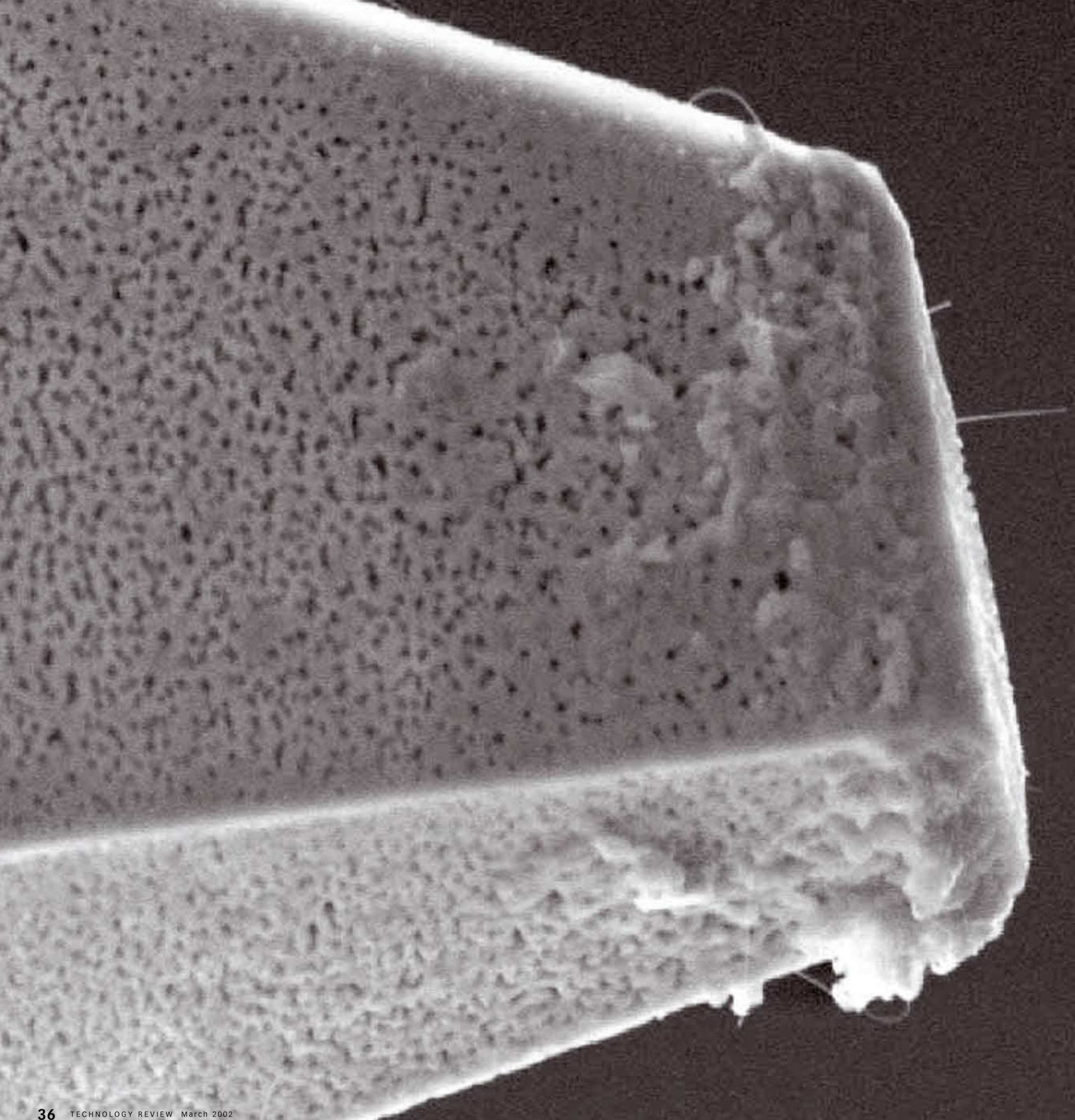


Nano hairs: A microscopic image shows a lone nanotube as it extends from a silicon tip. In a synthesis method developed by Harvard University's Charles Lieber, nanotubes grow out of tiny pores in the silicon.

the nanotube computer

TEN YEARS AFTER THEIR DISCOVERY, CARBON NANOTUBES ARE POISED TO LEAVE THE LAB AND ENTER THE REALM OF TECHNOLOGY. THAT COULD MEAN EVERYTHING FROM CHEAPER FLAT-PANEL TVS TO SUPERFAST COMPUTERS.

BY DAVID ROTMAN

In the hype-filled world of nanotechnology, Phaedon Avouris, head of IBM Research's nanoscience and technology group, has a reputation as a meticulous and somewhat skeptical scientist. By his own description, he is one of those researchers whom reporters call to get a "realistic assessment" of the latest nanotech breakthrough. These days, though, the IBM chemist sounds uncharacteristically upbeat.

The reason for his excitement can be seen in a microscopic image recently produced in his lab. It shows a thin thread draped over several thick gold electrodes. What is not so apparent is that the thread, a single carbon nanotube, has been modified and positioned so that it forms two types of transistors, each a few nanometers (billionths of a meter) in diameter—a hundred times smaller than the transistors now found on computer chips. What's more, the nanotube transistors work together as a logic gate, the fundamental computer component responsible for selectively routing electrical signals, transforming them into meaningful ones and zeroes.

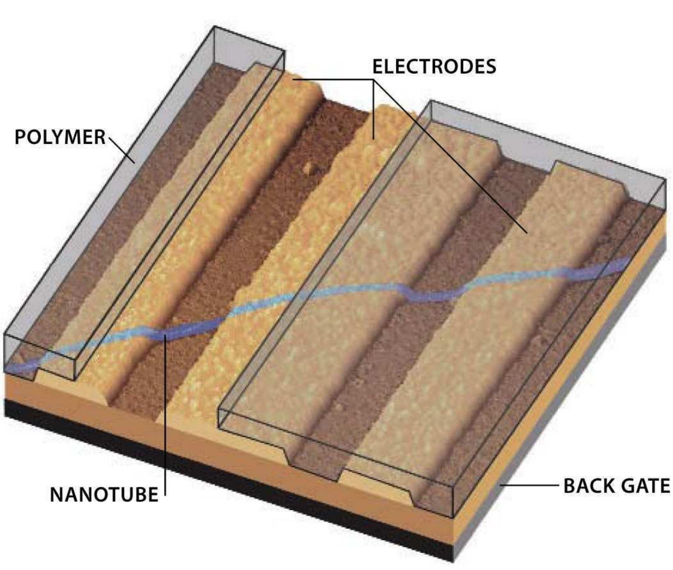
The IBM device is one of the first examples of electronic circuitry constructed out of individual molecules. And while it's merely a crude laboratory demonstration, its successful fabrication is nevertheless a further tantalizing clue that carbon nanotubes could one day replace silicon crystals as the building blocks for ultrafast, ultrasmall computers. More measurements are needed, says Avouris, "but our current results show, after taking into account difference in size, nanotube transistors show a performance superior to that of state-of-the-art silicon transistors."

Indeed, carbon nanotubes are, in theory at least, the ideal material for building tomorrow's nanoelectronics. And now, a little more than 10 years after their discovery, nanotubes seem ready to make the transition from exotic laboratory wonders to materials useful in actual technologies. Prototypes of nanotube devices are being tested in everything from full-color flat-panel TV screens to ultrabright outdoor lighting to a simpler, smaller x-ray machine; consumers could be shopping for a flat-screen TV that uses nanotubes as early as Christmas 2003.

But it is in computer memory and logic that nanotubes could have their greatest impact. Microelectronics now use silicon transistors with features as small as 130 nanometers across, which means that Intel can squeeze some 42 million of these transistors onto its Pentium 4 chip. However, it's getting harder—and far more expensive—to continue to shrink silicon devices. Using nanotubes or related materials called nanowires as tiny electronic switches would allow computer designers to cram billions of devices onto a chip. If these molecular transistors work—and that is still a big *if*—replacing silicon will likely take years. But the ambition, says Charles Lieber, a Harvard University chemist, is to build electronics with performance "orders of magnitude beyond silicon. We're trying to break with what is being done, to really change things."

A Logical Next Step

Microscopic image of a logic gate that IBM researchers built out of a single carbon nanotube (blue line). The exposed and unexposed segments of the nanotube form two different types of transistors.



NANO GEMS

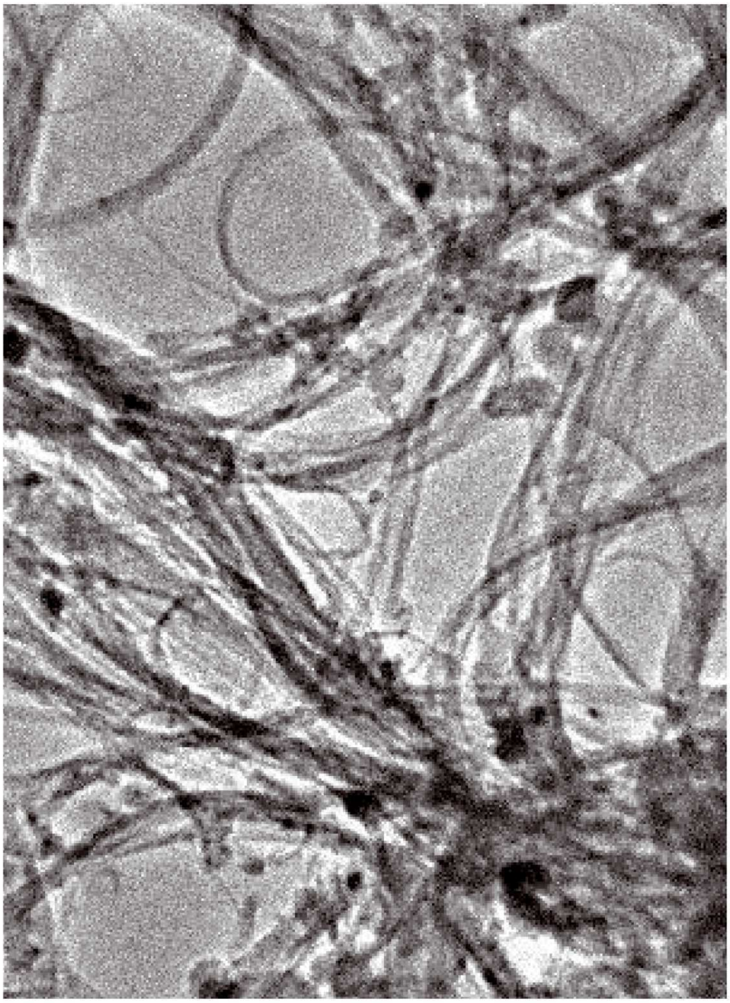
Carbon nanotubes are sometimes described as, basically, soot. In fact, they can be found among the deposits formed when electricity arcs between two carbon electrodes. But describing nanotubes as soot is like saying diamonds are nothing more than compressed coal. Each carbon atom in a nanotube is naturally positioned in a chicken-wire lattice that wraps into a hollow pipe. This molecular perfection gives nanotubes their long list of unusual—and potentially useful—properties.

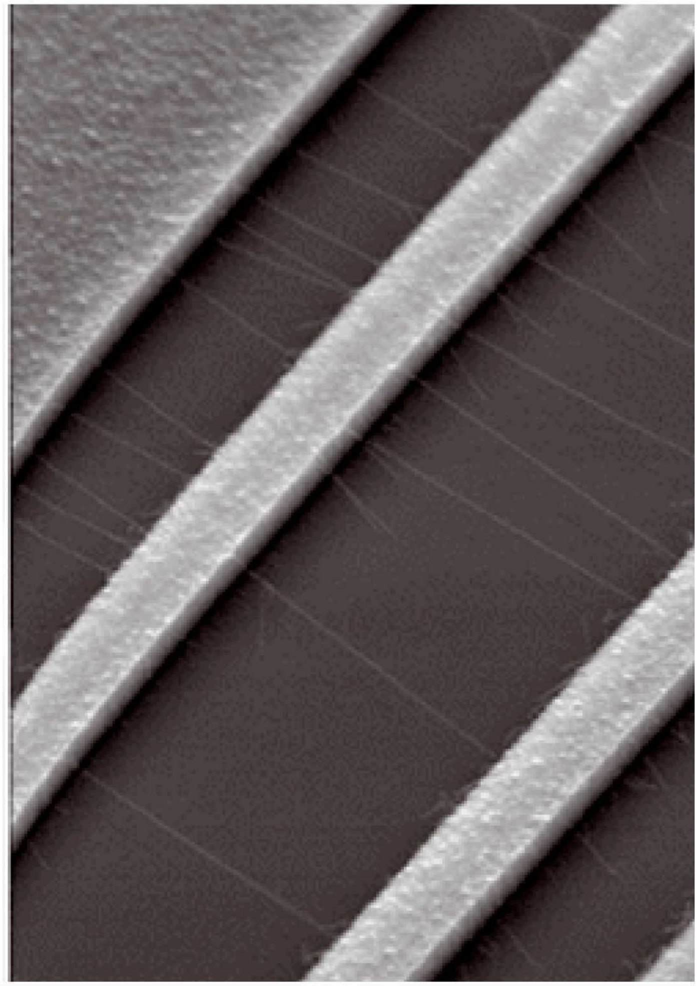
Knowledge of the carbon structure dates back to 1985, when researchers at Rice University in Houston discovered soccer-ball-shaped carbon molecules called fullerenes. Following the discovery, theoretical physicists predicted that tubular versions of this same carbon structure could exist and that such molecules would have a number of enticing properties, such as excellent electrical conductivity. Mildred Dresselhaus, a physicist at MIT, recalls calculating the likely properties of what she called carbon "nanotubules." "We didn't have them yet," she says, but it was still possible to speculate on "what they might be like."

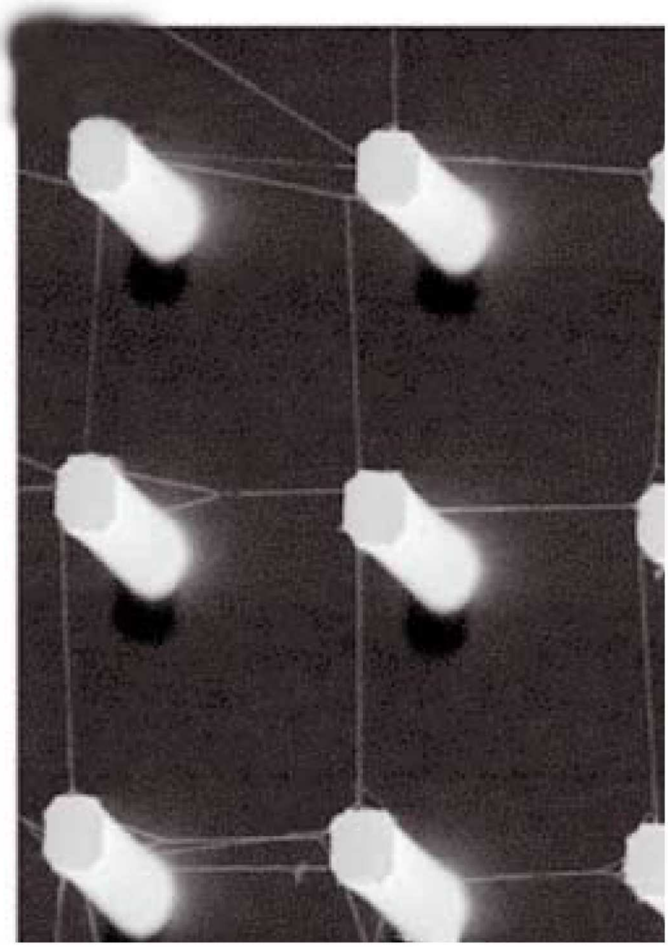
Spurred by the growing excitement over the new form of carbon, Sumio Iijima, a physicist at NEC Research in Tsukuba, Japan, went hunting for carbon nanotubes in late 1990. Trained in electron microscopy, Iijima says he was used to "looking at all kinds of graphite and small diamonds." Iijima also says he was "quite lucky" in being experienced in observing needlelike microscopic shapes; his PhD had been on microscopic whiskers of silver. Several months after beginning his search, Iijima hit pay dirt. "When I saw all these needles of carbon, immediately I came to the right answer," he remembers.

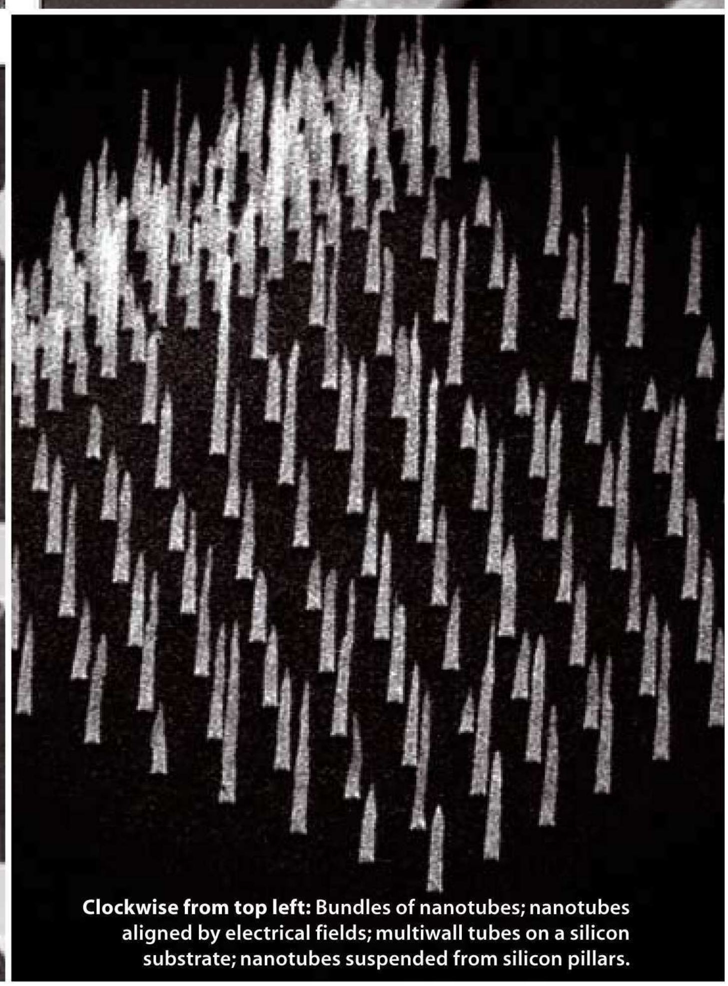
What Iijima was peering at were "multiwall" nanotubes—long carbon molecules stuffed one within another like nested Russian Matryoshka dolls. In 1993, Iijima and his NEC coworkers, and another group at IBM Research in San Jose, CA, separately produced an even more exquisite version: nanotubes whose walls were only a single atom thick.

The new structures didn't disappoint. One early research finding was that in the presence of an electric field nanotubes emit electrons from their extremely fine tips. Any number of electrically conductive materials will, when a high enough volt-









Clockwise from top left: Bundles of nanotubes; nanotubes aligned by electrical fields; multiwall tubes on a silicon substrate; nanotubes suspended from silicon pillars.

CLOCKWISE FROM TOP LEFT: COURTESY OF ANDREAS THESS, RICE UNIVERSITY; COURTESY OF HONGJIE DAI; COURTESY OF BOSTON COLLEGE; COURTESY OF HONGJIE DAI

age is applied, spit out electrons. Nanotubes can do this at remarkably low voltages because of their extreme sharpness. So carbon nanotubes are almost perfect for building tiny, efficient electron emitters. They can direct focused electron beams at very small targets—say, a pixel of a display.

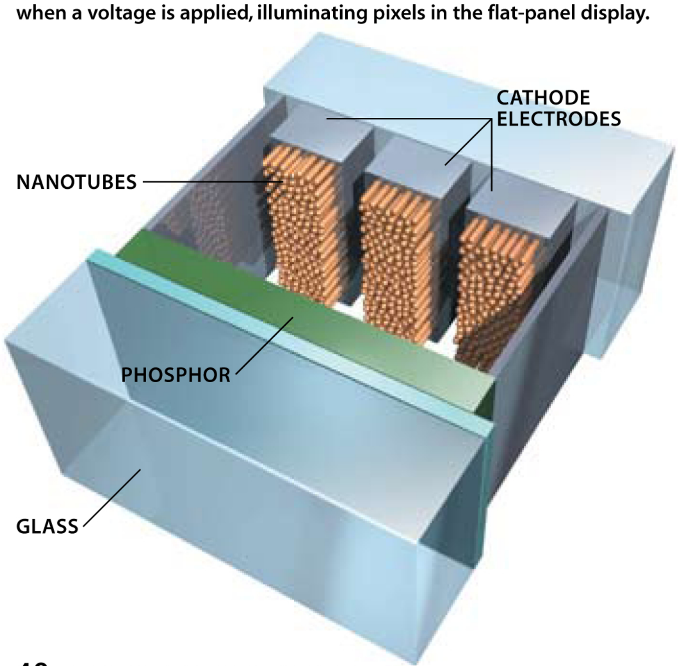
As many as two dozen electronics firms, including Samsung and Motorola, are now racing to develop flat-panel displays that use nanotubes. TV screens and the computer displays that sit on most desktops are holdovers of the vacuum-tube era. These clear and relatively cheap displays use cathode-ray tubes, in which electrically heated wires shoot electron beams onto a phosphor-coated screen, which in turn lights up. The problem is that the picture tube uses a lot of power, and it must be deep enough to allow the electron guns to project to the whole screen—hence the fat bulge in back of most TVs. In contrast, screens using an array of nanotubes can put tiny electron emitters behind each pixel and therefore can be far thinner.

At first glance, the prototype 13-centimeter screen made at the Samsung Advanced Institute of Technology in Suwon, South Korea, doesn't look much different than any other small TV. Smiling actors flash across its face in a slickly made promo. But that similarity is exactly the point. If Samsung researchers can turn this prototype—which uses nanotubes to bombard the phosphor screen with electrons—into a TV as bright and clear as the one in your living room, they could capture the best of both display worlds: cheap as cathode-ray tubes and thin as far more expensive liquid-crystal or plasma display TVs.

Samsung expects to have full-color prototypes capable of the resolution needed for high-definition television this winter and an 81-centimeter TV ready for the market by late 2003 or early 2004, says Jong Min Kim, vice president of research at the Samsung Advanced Institute of Technology. Key to success in the \$100 billion display market, he says, will be getting manufacturing costs of the nanotube TVs low enough that they can compete with cathode-ray-tube models. "First we will try to attack the TV market, then we'll go after the computers," says Kim.

Pixel Perfect

Arrays of nanotubes directed toward a phosphor screen emit electrons when a voltage is applied, illuminating pixels in the flat-panel display.



INSTANT TURN-ON

Far from the large corporate labs working on nanotube TVs is a tiny Woburn, MA-based startup called Nantero, whose employees hope to take on another multibillion-dollar market—computer memory. Sitting in Nantero's conference room, which also serves as a front entrance, lobby and kitchenette, cofounder and chief scientist Tom Rueckes seems both anxious and excited. And well he should be. The year-old company is promising a high-density nanotube-based memory that would revolutionize the market. And it claims it will have this breakthrough working within two years. "Imagine," says Rueckes, "having several gigabits of memory at your fingertips that is instantly on."

Indeed, the most attractive aspect of the Nantero memory is that it will be "nonvolatile." Conventional dynamic random-access memory (DRAM), the short-term electronic memory that a computer uses to run its operating systems and programs, holds information only as long as the power is on. That's why a PC needs to be booted up: the machine has to rewrite stored information from the hard drive onto the electronic memory. Nonvolatile memory means never booting up again. Eventually, if the storage capacity of nonvolatile memory chips gets large enough, they could make magnetic hard drives obsolete.The best existing DRAM can hold about one gigabyte of data. Within two years, Nantero expects to have a nanotube-based nonvolatile memory chip with several gigabytes of capacity.

The nanotube memory is based on an ingenious, though strikingly simple, design that Rueckes came up with while a PhD student under Lieber at Harvard. An array of parallel nanotubes is suspended just a few nanometers above a perpendicular array lying on a substrate; each intersection of the cross-arrays represents a potential bit of memory. When an applied electrical force stretches a tube in the top array close enough to a lower tube, they physically bind and a current can flow between them; the switch is on and stays on even when the power is turned off. Because each bit of memory is so small, a centimeter-sized chip based on the design could have, in theory, terabits (a trillion bits) of nonvolatile memory.

The goal is to turn this laboratory design into real technology as quickly as possible. Rueckes declines to detail exactly what has been built so far, except to say that "components of it are working." But he adds that the strategy is to integrate nanotube memory with conventional electronics. "We want to come up with a product that can be manufactured with existing technology," he says.

Such nonvolatile memory would change how people use their computers, doing away with those tedious minutes spent booting up. But the real prize in nanoelectronics—the one that will make people truly forget about silicon—is the logic circuits that are the brains of computers. Moore's Law, the oft-cited 1965 prediction by Intel cofounder Gordon Moore that the number of transistors on a chip would double every 18 months, has held for more than three and a half decades. But experts predict that within a decade or so, it may well be impossible to make silicon transistors small enough to continue to uphold Moore's Law.

There is no shortage of technologies proposed to eventually replace silicon, from ways to use complex organic molecules as transistors to "quantum computing" *(see "Beyond Silicon,"* TR *May/June 2000)*. But carbon nanotubes are emerging as a leading candidate. Not only are they the right size, with the right elec-

SLIM FILMS

tronic properties, but their compatibility with existing semiconducting materials raises the prospect that, over the next decade, it may be possible to gradually integrate them with conventional silicon technology. That could give nanotubes the inside track, since most chip makers are no more anxious than Rueckes to overthrow existing manufacturing techniques.

The first working transistor built from carbon nanotubes appeared in 1998. A little more than a nanometer in size, it was a remarkable achievement from a physics point of view. It was also the type of breakthrough that is easy for computer scientists and electrical engineers to shrug off. What good, after all, is a single transistor? But the recent fabrication of a series of transistors arranged into crude circuits—reported separately by Avouris and colleagues at IBM and, in a different version, by Cees Dekker of the University of Delft in the Netherlands a few months later—could allay some of that skepticism. "Before we had a single unit. Now we have made the type of thing that electrical engineers need in order to demonstrate molecular memory and logic," says Dekker.

It may be the type of circuit that an electrical engineer can recognize, but huge challenges remain in scaling it up for use in practical devices. In particular, the fact that nanotubes can be either metallic like copper or semiconducting is a mixed blessing. The schizo nature of nanotubes means fabricating logic devices is difficult, because investigators are unable to selectively make only metallic or semiconducting materials. "The big problem is that the synthesis methods are fairly primitive," says Harvard's Lieber. "If you *could* make all semiconducting or all metallic, you would be far ahead of where we are today in thinking about building electronics. It would be a revolutionary advance."

But while the split personality of nanotubes may be a "nuisance" for technologists now trying to build devices, says Dekker, "in the long term it *must* be an advantage." Nanotubes in some future computer, for example, could serve as both metal wires and semiconducting transistors, creating a highly integrated machine. "These molecules are completely unique," says Dekker, who holds that it is just a matter of time before researchers learn to manipulate their special properties.

MATERIALS OF FAITH

One direct benefit of a decade of research on carbon nanotubes has been a growing understanding of nano materials in general—and an ever growing belief in their vast practical potential. "Carbon nanotubes have opened peoples' eyes to the possibilities," says Philip Collins, a researcher at Covalent Materials in Emeryville, CA, a nano materials startup. In particular, researchers are now pursuing ultrasmall wires and nanotubes composed of materials other than carbon, including some of the very same ones that many researchers had hoped to replace—silicon and other conventional semiconductors. These new nanowires are slightly larger than carbon nanotubes and are not as strong or conductive; but at least for now they are easier to make and manipulate. For chemists and physicists, says Collins, there is now a whole new, nanotech version of the periodic table to play with. "People are just beginning to investigate all different kinds of nanotubes and nanowires," he says.

Venturing into Nano

Given the investment vacuum left by the demise of the dot-com market, it was bound to happen: the venture capital community has discovered nanotech.

A wave of nanotech companies started up in 2001, bankrolled by venture capitalists suddenly eager to fund tiny biological sensors and nanoscale memory bits. According to a survey last October by the NanoBusiness Alliance, a New York-based group that bills itself as nanotech's first industry association, venture and private capital investment in nanotechnology will reach $1 billion this year, up from a mere $100 million in 1999. The first dedicated nanotech venture funds are appearing as well. Japan's Mitsubishi last summer announced a $100 million fund to invest in the emerging technology.

Added to this cash flow is the almost $520 million the U.S. government expects to spend in fiscal 2002 to support nanotech research. Japan, the European Union and even South Korea also have ambitious spending plans. The infusion of dollars, euros, yen and won has transformed nanotech from an esoteric, albeit promising, research field into one of today's most visible technologies.

It's a transformation that has some leading nanotech researchers scratching their heads. "I have many cold calls from venture capitalists displaced by the dot-com era and looking for the next big thing. A lot are focusing on nanotech as the next big payday," says R. Stanley Williams, head of Hewlett-Packard's quantum science research labs *(see "Computing after Silicon," TR September/October 1999)*. The danger, says Williams, is that while there are "real gems" among the early nanotech startups, most nanotechnology work is still in the research phase, far from commercialization. The field, he sums up, is "where biotech was about 15 years ago."

As happened in the biotech industry, the successful nanotech companies will likely arise from the work of a select group of top-notch university researchers. For venture capitalists, the trick is to figure which of today's academic projects will turn into real technology. The quality and amount of academic research in nanotech is impressive, says Jennifer Fonstad, a managing director at Redwood, CA-based Draper Fisher Jurvetson, a venture capital firm that has invested in Woburn, MA-based Nantero and several other nanotech startups. Indeed, says Fonstad, during the last six months of 2001 she was presented with 60 to 70 business plans from those seeking financial backing "in this space." But echoing Williams's sentiments, she notes that the abundance of research efforts doesn't necessarily "translate into business opportunities in the near and medium term. It's actually a fairly small field in terms of the technology," she says.

And despite nanotech's growing visibility, many venture investors remain justifiably cautious. "A lot are looking," says Fonstad, "but it's too early for many to make an investment."

Timing, of course, is everything for an investor. Peter Schwartz, a venture capitalist at Alta Partners in San Francisco, which funded the startup of Emeryville, CA-based Covalent Materials, says his strategy is to find research just as it is beginning to focus "on a particular application." The expectation is a commercial product in five years. "Any longer time frame," he suggests, means "it's not such a great investment."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ENTERPRISE
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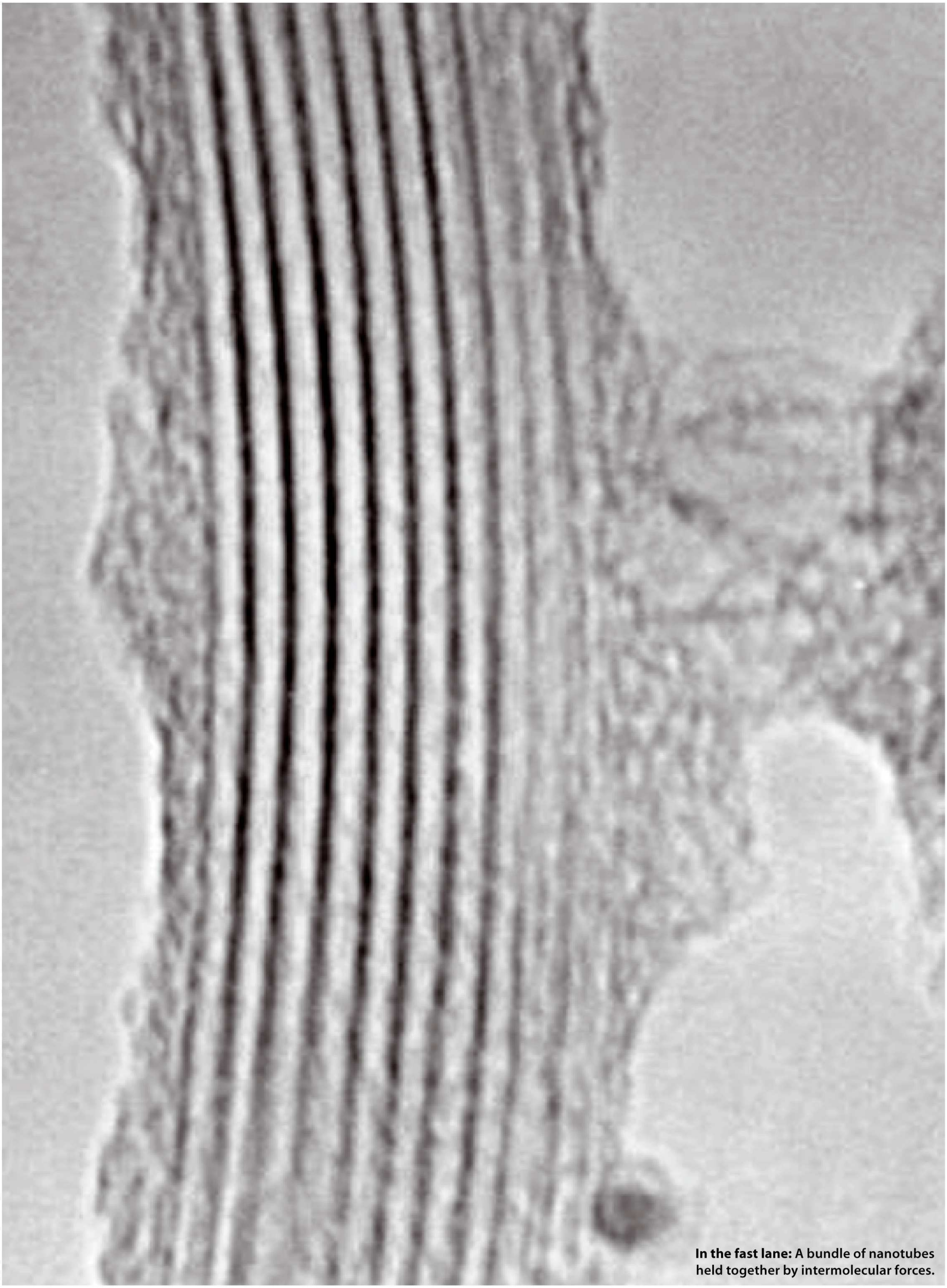

In the fast lane: A bundle of nanotubes held together by intermolecular forces.

COURTESY OF PAVEL NIKOLAEV/RICE UNIVERSITY

A pioneer in carbon nanotubes, Lieber, for one, has over the last year published a string of scientific reports on how to use various nanowires fashioned from noncarbon materials to make everything from microscopic biological sensors to tiny light-emitting diodes to nano logic gates. Last fall, for example, his research group at Harvard reported constructing logic circuits from silicon and gallium nitride nanowires. "With control of the electronic properties, we can start to build up complex devices," says Lieber. "Nanowires allow us to be a little more free."

All that leaves many of those who have spent the last decade studying carbon nanotubes encouraged by the expanding possibilities. The technology winners and losers are still far from certain; as MIT's Dresselhaus puts its, "When you start out in a new field in technology, you dream of many different things. Some work." But regardless of this uncertainty, the attention of many nanotube and nanowire researchers is now focused on how to turn the novel properties of these unusual materials into the basis for devices that can compete in the real world *(see "Nanotube Ten to Watch," below)*.

In making nanotubes into computer components, "there are still significant scientific questions to be answered," says IBM's Avouris. But he predicts that in a couple of years his group will have answered enough of those questions to recommend whether the computer giant should go ahead with a significant effort to develop nanoelectronics based on carbon nanotubes. If the prognosis is promising, the project will be passed on to IBM's formidable team of computer engineers and designers. "Then it's out of our hands," says Avouris.

Even if all goes well, most experts predict it will be at least a decade before nanotubes become a significant part of computers. Challenging the supremacy of silicon is an enormous technical and financial task that will take far more than some promising scientific advances. It will take equally impressive advances in manufacturing and computer design. "Nanotubes can be used as transistors, logic and memory; all that has been demonstrated now," says Hongjie Dai, a chemist and nanotube researcher at Stanford University. "The question now is, 'How practical can these [nanotube] devices be?'"

Dai is not exactly waiting around for the answer. Late last year, he started up a company called Molecular Nanosystems to capitalize his research group's advances in making highly uniform arrays of nanotubes. While nanotube components for computers may be years away, suggests Dai, other electronic applications are not far off. By the end of this year, he predicts, his company will have prototypes of ultrasensitive, nanotube-based chemical and biological detectors for use in everything from drug discovery to antiterrorism surveillance, as well as a better nanotube technology for flat-panel displays.

Dai's is just the kind of optimism that is fueling hopes at the hundreds of nanotube labs around the world. If the ambitions of these far-flung research groups pay off, carbon nanotubes and other nanowires will not only have altered how chemists and physicists perceive the nano world, they will, over the next decade, begin to change the world of electronics. TR

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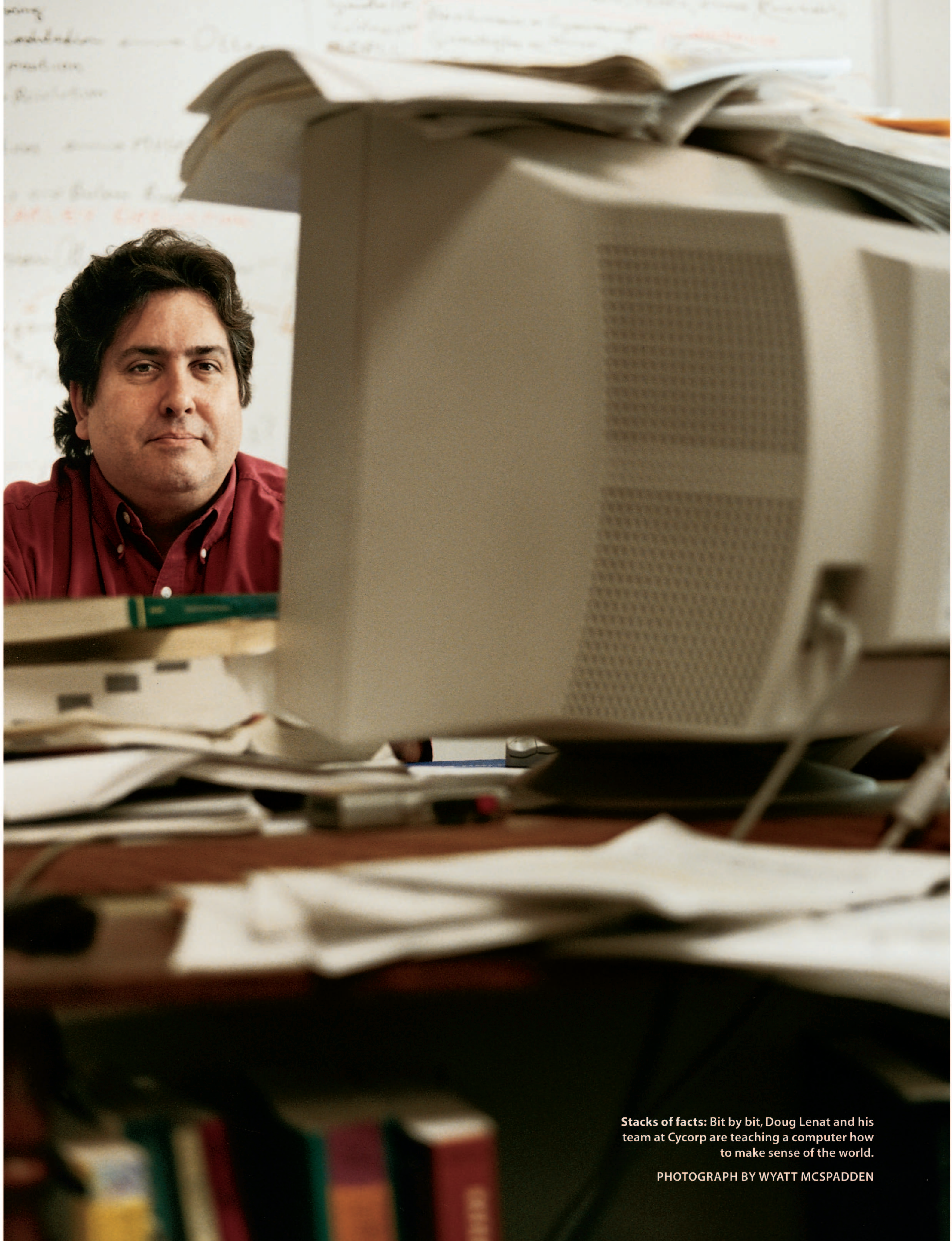
Nanotube Ten to Watch

COMPANY	STRENGTHS	STRATEGY
Carbon Nanotechnologies (Houston, TX)	Exclusive license for technology developed at Rice University by Nobel Prize winner Richard Smalley	Produce and sell commercial-scale quantities of nanotubes
Covalent Materials (Emeryville, CA)	Founded by University of California, Berkeley, physicists Alex Zettl and Marvin Cohen	Rationally design and synthesize novel nanotubes and nanowires
IBM Research (Yorktown Heights, NY)	Team led by Phaedon Avouris has made numerous nanotube advances	Build integrated circuits out of nanotubes
Ise Electronics (Mie, Japan)	Collaboration with Yahachi Saito, a leading nanotube researcher at Mie University	Develop nanotube-based field emission devices for outdoor displays
Nantero (Woburn, MA)	Founded on technology licensed from Harvard University, has raised $6 million in venture funding	Fabricate nonvolatile electronic memory using nanotubes
Molecular Nanosystems (Palo Alto, CA)	Cofounded by Stanford University researcher Hongjie Dai, has technology for growing arrays of nanotubes	Use proprietary synthesis technology to make arrays of biological and chemical sensors and field emission devices
Motorola research labs (Tempe, AZ)	Research team experienced in developing field emission displays	Research on flat-panel displays using nanotubes
Nanosys (Palo Alto, CA)	Licensing agreement with Harvard University for nanowire technology developed by Charles Lieber; has raised $1.7 million in early investments	Build up a portfolio of nanodots, nanotubes and nanowires for optoelectronics and nanoelectronics
NEC Research (Tsukuba, Japan)	Team headed by Sumio Iijima, discoverer of nanotubes	Develop nanotubes as electrodes for use in fuel cells
Samsung Advanced Institute of Technology (Suwon, South Korea)	One of the largest corporate research groups dedicated to developing nanotube displays	Commercialize flat-screen TVs based on field emission devices using carbon nanotubes



Stacks of facts: Bit by bit, Doug Lenat and his team at Cycorp are teaching a computer how to make sense of the world.

PHOTOGRAPH BY WYATT MCSPADDEN

BY MICHAEL HILTZIK

A.I. REBOOTS

2001 HAS COME AND GONE, WITH DREAMS OF A HAL-LIKE COMPUTER LONG SINCE ABANDONED. BUT IN SCALING BACK THEIR PROMISES, ARTIFICIAL-INTELLIGENCE RESEARCHERS ARE FINALLY STARTING TO SCORE SIGNIFICANT SUCCESSES.

It was the spring of 2000. The scene was a demonstration of an advanced artificial-intelligence project for the U.S. Department of Defense; the participants were a programmer, a screen displaying an elaborate windowed interface and an automated "intelligence"—a software application animating the display. The subject, as the programmer typed on his keyboard, was anthrax.

Instantly the machine responded: "Do you mean Anthrax (the heavy-metal band), anthrax (the bacterium) or anthrax (the disease)?"

"The bacterium," was the typed answer, followed by the instruction, "Comment on its toxicity to people."

"I assume you mean *people* (homo sapiens)," the system responded, reasoning, as it informed its programmer, that asking about *People* magazine "would not make sense."

Through dozens of similar commonsense-ish exchanges, the system gradually absorbed all that had been published in the standard bioweapons literature about a bacterium then known chiefly as the cause of a livestock ailment. When the programmer's input was ambiguous, the system requested clarification. Prompted to understand that the bacterium anthrax somehow fit into the higher ontology of biological threats, it issued queries aimed at filling out its knowledge within that broader framework, assembling long lists of biological agents, gauging their toxicity and strategies of use and counteruse. In the process, as its proud creators watched, the system came tantalizingly close to that crossover state in which it knew what it did not know and sought, without being prompted, to fill those gaps on its own.

The point of this exercise was not to teach or learn more about anthrax; the day when the dread bacterium would start showing up in the mail was still 18 months in the future. Instead, it was to demonstrate the capabilities of one of the most promising and ambitious A.I. projects ever conceived, a high-performance knowledge base known as Cyc (pronounced "psych"). Funded jointly by private corporations, individual investors and the Pentagon's Defense Advanced Research Projects Agency, or DARPA, Cyc represents the culmination of an 18-year effort to instill common sense into a computer program. Over that time its creator, the computer scientist Douglas B. Lenat, and his cadres of programmers have infused Cyc with 1.37 million assertions—including names, abstract concepts, descriptions and root words. They've also given Cyc a common-sense inference engine that allows it, for example, to distinguish among roughly 30 definitions of the word "in" (being *in* politics is different from being *in* a bus).

Cyc and its rival knowledge bases are among several projects that have recently restored a sense of intellectual accomplishment to A.I.—a field that once inspired dreams of sentient computers like *2001: A Space Odyssey*'s HAL 9000 and laid claim to the secret of human intelligence, only to be forced to back off from its ambitions after years of experimental frustrations. Indeed, there is a palpable sense among A.I.'s faithful—themselves survivors of a long, cold research winter—that their science is on the verge of new breakthroughs. "I believe that in the next two years things will be dramatically changing," says Lenat.

It may be too early to declare that a science with such a long history of fads and fashions is experiencing a new springtime, but a greater number of useful applications are being developed now than at any time in A.I.'s more than 50-year history. These include not only technologies to sort and retrieve the vast quantity of information embodied in libraries and databases, so that the unruly jungle of human knowledge can be tamed, but improvements in system interfaces that allow humans and computers to communicate faster and more directly with each other—through, for instance, natural language, gesture, or facial expression. And not only are artificial-intelligence-driven devices venturing into places that might be unsafe for humans—one fleet of experimental robots with advanced A.I.-powered sensors assisted the search for victims in the World Trade Center wreckage last September—they're showing up in the most mundane of all environments, the office. Commercial software soon to reach the market boasts "smart" features that employ A.I.-based Bayesian probability models to prioritize e-mails, phone messages and appointments according to a user's known habits and (presumed) desires.

These and other projects are the talk of artificial-intelligence labs around the United States. What one does not hear much about anymore, however, is the traditional goal of understanding and replicating human intelligence.

"Absolutely none of my work is based on a desire to understand how human cognition works," says Lenat. "I don't understand, and I don't care to understand. It doesn't matter to me how people think; the important thing is what we know, not how do we know it."

One might call this trend the "new" A.I., or perhaps the "new new new" A.I., for in the last half-century the field has redefined itself too many times to count. The focus of artificial intelligence today is no longer on psychology but on goals shared by the rest of computer science: the development of systems to augment human abilities. "I always thought the field would be healthier if it could get rid of this thing about 'consciousness,'" says Philip E. Agre, an artificial-intelligence researcher at the University of California, Los Angeles. "It's what gets its proponents to over-promise." It is the scaling back of its promises, oddly enough, that has finally enabled A.I. to start scoring significant successes.

BRILLIANCE PROVES BRITTLE

To a great extent, artificial-intelligence researchers had no choice but to exchange their dreams of understanding intelligence for a more utilitarian focus on real-world applications. "People became frustrated because so little progress was being made on the scientific questions," says David L. Waltz, an artificial-intelligence researcher who is president of the NEC Research Institute in Princeton, NJ. "Also, people started expecting to see something useful come out of A.I." And "useful" no longer meant "conscious."

For example, the Turing test—a traditional trapping of A.I. based on British mathematician Alan Turing's argument that to be judged truly intelligent a machine must fool a neutral observer into believing it is human—came to be seen by many researchers as "a red herring," says Lenat. There's no reason a smart machine must mimic a human being by sounding like a person, he argues, any more than an airplane needs to mimic a bird by flapping its wings.

Of course, the idea that artificial intelligence may be on the verge of fulfilling its potential is something of a chestnut: A.I.'s 50-year history is nothing if not a chronicle of lavish promises and dashed expectations. In 1957, when Herbert Simon of Carnegie Tech (now Carnegie Mellon University) and colleague Allen Newell unveiled Logic Theorist—a program that automatically derived logical theorems, such as those in Alfred North Whitehead and Bertrand Russell's *Principia Mathematica,* from given axioms—Simon asserted extravagantly that "there are now in the world machines that think, that learn and that create." Within 10 years, he continued, a computer would beat a grandmaster at chess, prove an "important new mathematical theorem" and write music of "considerable aesthetic value."

"This," as the robotics pioneer Hans Moravec would write in 1988, "was an understandable miscalculation." By the mid-1960s, students of such artificial-intelligence patriarchs as John McCarthy of Stanford University and Marvin Minsky of MIT were producing programs that played chess and checkers and managed rudimentary math; but they always fell well short of grandmaster caliber. Expectations for the field continued to diminish, so much so

that the period from the mid-1970s to the mid-1980s became known as the "A.I. winter." The best expert systems, which tried to replicate the decision-making of human experts in narrow fields, could outperform humans at certain tasks, like the solving of simple algebraic problems, or the diagnosis of diseases like meningitis (where the number of possible causes is small). But the moment they moved outside their regions of expertise they tended to go seriously, even dangerously, wrong. A medical program adept at diagnosing human infectious diseases, for example, might conclude that a tree losing its leaves had leprosy.

Even in solving the classic problems there were disappointments. The IBM system Deep Blue finally won Simon's 40-year-old wager by defeating chess grandmaster Garry Kasparov in 1997, but not in the way Simon had envisioned. "The earliest chess programs sought to duplicate the strategies of grandmasters through pattern recognition, but it turned out that the successful programs relied more on brute force," says David G. Stork, chief scientist at Ricoh Innovations, a unit of the Japanese electronics firm, and the editor of *HAL's Legacy*, a 1996 collection of essays assessing where the field stood in relation to that paradigmatic, if fictional, intelligent machine. Although Deep Blue did rely for much of its power on improved algorithms that replicated grandmaster-style pattern recognition, Stork argues that the system "was evaluating 200 million board positions per second, and that's a very un-humanlike method."

Many A.I. researchers today argue that any effort to replace humans with computers is doomed. For one thing, it is a much harder task than many pioneers anticipated, and for another there is scarcely any market for systems that make humans obsolete. "For revenue-generating applications today, replacing the human is not the goal," says Patrick H. Winston, an MIT computer scientist and cofounder of Ascent Technology, a private company based in Cambridge, MA, that develops artificial-intelligence applications. "We don't try to replace human intelligence, but complement it."

COMMONSENSE SOLUTIONS

"What we want to do is work toward things like cures for human diseases, immortality, the end of war," Doug Lenat is saying. "These problems are too huge for us to tackle today. The only way is to get smarter as a species—through evolution or genetic engineering, or through A.I."

We're in a conference room at Cycorp, in a nondescript brick building nestled within an Austin, TX, industrial park. Here, teams of programmers, philosophers and other learned intellectuals are painstakingly inputting concepts and assertions into Cyc in a Socratic process similar to that of the anthrax dialogue above. Surprisingly, despite the conversational nature of the interaction, the staff seems to avoid the layman's tendency to anthropomorphize the system.

"We don't personalize Cyc," says Charles Klein, a philosophy PhD from the University of Virginia who is one of Cycorp's "ontologists." "We're pleased to see it computing commonsense outputs from abstract inputs, but we feel admiration toward it rather than warmth."

That's a mindset they clearly absorb from Lenat, a burly man of 51 whose reputation derives from several programming breakthroughs in the field of heuristics, which concerns rules of thumb for problem-solving—procedures "for gathering evidence, making hypotheses and judging the interestingness" of a result, as Lenat explained later. In 1976 he earned his Stanford doctorate with Automated Mathematician, or AM, a program designed to "discover" new mathematical theorems by building on an initial store of 78 basic concepts from set theory and 243 of Lenat's heuristic rules. AM ranged throughout the far reaches of mathematics before coming to a sudden halt, as though afflicted with intellectual paralysis. As it happened, AM had been equipped largely with heuristics from finite-set theory; as its discoveries edged into number theory, for which it had no heuristics, it eventually ran out of discoveries "interesting" enough to pursue, as ranked by its internal scoring system.

AM was followed by Eurisko (the present tense of the Greek *eureka*, and root of the word *heuristic*), which improved on Automated Mathematician by adding the ability to discover not only new concepts but new heuristics. At the 1981 Traveller Trillion Credit Squadron tournament, a sort of intellectuals' war game, Eurisko defeated all comers by outmaneuvering its rivals' lumbering battleships with a fleet of agile little spacecraft no one else had envisioned. Within two years the organizers were threatening to cancel the tournament if Lenat entered again. Taking the cue and content with his rank of intergalactic admiral, he began searching for a new challenge.

The task he chose was nothing less than to end A.I.'s long winter by overcoming the limitations of expert systems. The reason

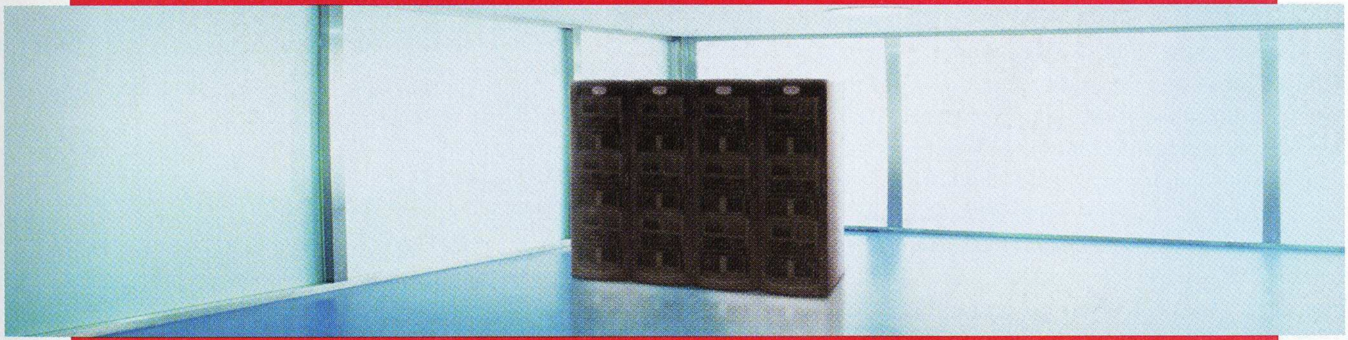
Important Players in A.I.

Artificial intelligence is becoming so deeply embedded in computer applications of all kinds that many prominent companies have created A.I. teams. Here are five commercial entities doing important work in the field.

NAME	LOCATION	FOCUS
Cycorp	Austin, TX	"Common sense" processing and ontologies for large databases
IBM (Watson Research Center)	Yorktown Heights, NY	Data mining and intelligent-agent development
iRobot	Somerville, MA	Robots chiefly for industrial and military applications
Microsoft (Microsoft Research)	Redmond, WA	Intelligent assistants and user interfaces for the Windows operating system and Office software suite
NEC (NEC Research Institute)	Princeton, NJ	Visual recognition, natural-language processing, learning algorithms
SRI International	Menlo Park, CA	Machine vision, virtual reality, natural-language processing

AGRICULTURAL PRODUCTION: AUTOMATED IN 1793

MANUFACTURING: AUTOMATED IN 1913



THE CORPORATE DATA CENTER: AUTOMATED IN 2002

THE COMPAQ ADAPTIVE INFRASTRUCTURE IS ABOUT TO CHANGE EVERYTHING.

Technology has automated just about everything these days. But curiously, the corporate data center has lagged behind. There, highly paid people still spend inordinate amounts of time doing things like manual fault searches and fingernail-ripping server management tasks. It's more than ironic. It's enormously counterproductive. Because every initiative a corporation undertakes—whether it's in operations, marketing, accounts or HR—goes through the data center.

But the new Compaq Adaptive Infrastructure will take your critical initiatives farther and faster than ever before. Its next-generation ProLiant™ Blade-Line server technology features innovative architecture that conserves space and resources by multiplying performance per square foot of data center. And its ProLiant Essentials management software offers levels of control scaled to your needs so you can rapidly adapt to change, remotely deploying new technology—and redeploying existing technology—in the time it takes to click on a mouse.

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COMPAQ
Inspiration Technology

a trained geologist is easier for a computer system to replicate than a six-year-old child is not a secret: it's because the computer lacks the child's common sense—that collection of intuitive facts about the world that are hard to reduce to logical principles. In other words, it was one thing to infuse a computer with data about global oil production or meningitis, but quite another to teach it all the millions of concepts that humans absorb through daily life—for example, that red is not pink or that rain will moisten a person's skin but not his heart. "It was essentially like assembling an encyclopedia, so most people spent their time talking about it, rather than doing it," Lenat says.

And so Cyc was born. Lenat abandoned a tenure-track position at Stanford to launch Cyc under the aegis of Microelectronics and Computing Technology, an Austin-based research consortium. Now, 18 years later, Cyc ranks as by far the most tenacious artificial-intelligence project in history and one far enough advanced, finally, to have generated several marketable applications. Among these is CycSecure, a program to be released this year that combines a huge database on computer network vulnerabilities with assumptions about hacker activities to identify security flaws in a customer's network before they can be exploited by outsiders. Lenat expects Cyc's common-sense knowledge base eventually to underpin a wide range of search engines and data-mining tools, providing the sort of filter that humans employ instinctively to discard useless or contradictory information. If you lived in New York and you queried Cyc about health clubs, for example, it would use what it knows about you to find information about clubs near your home or office, screening out those in Boston or Bangor.

Numerous other promising applications of the new A.I.—such as advanced robotics and the "Semantic Web," a sophisticated way of tagging information on Web pages so that it can be understood by computers as well as human users *(see "A Smarter Web,"* TR *November 2001)*—share Lenat's focus on real-world applications and add to the field's fresh momentum. Searching the World Trade Center wreckage, for example, provided a telling test for the work of the Center for Robot-Assisted Search and Rescue in Littleton, CO, a nonprofit organization founded by West Point graduate John Blitch, who believes that small, agile robots can greatly aid search-and-rescue missions where conditions remain too perilous for exclusively human operations. Having assembled for a DARPA project a herd of about a dozen robots—with lights, video cameras and tanklike treads mounted on bodies less than 30 centimeters wide—he brought them to New York just after September 11. Over the next week Blitch deployed the robots on five forays into the wreckage—during which their ability to combine data arriving from multiple sensors helped find the bodies of five buried victims.

SENDING CLIPPY BACK TO SCHOOL

The deployment of A.I. in applications like robotic search and rescue is at an early stage, but that's not true on other fronts. One of the busiest artificial-intelligence labs today is at Microsoft Research, where almost everything is aimed at conjuring up real-world applications.

Here several teams under the direction of Eric Horvitz, senior researcher and manager of the Adaptive Systems and Interaction group, are working to improve the embedded functions

Where no man can go: A.I.-powered robots built by John Blitch and his team helped search the World Trade Center wreckage.

PHOTOGRAPH BY WALTER SMITH


Foster-Miller
SAIC
SONY

Whiteboard to Windows: Eric Horvitz and his team at Microsoft write A.I. algorithms that make the company's software friendlier.

PHOTOGRAPH BY BRYCE DUFFY

of Microsoft products. Several of the group's A.I.-related advances have found their way into Windows XP, the latest iteration of Microsoft's flagship operating system, including a natural-language search assistant called Web Companion and "smart tags," a feature that automatically turns certain words and phrases into clickable Web links and entices readers to explore related sites.

To demonstrate where things are heading, Horvitz fires up the latest in "smart" office platforms. It's a system that analyzes a user's e-mails, phone calls (wireless and land line), Web pages, news clips, stock quotes—all the free-floating informational bric-a-brac of a busy personal and professional lifestyle—and assigns every piece a priority based on the user's preferences and observed behavior. As Horvitz describes the system, it can perform a linguistic analysis of a message text, judge the sender-recipient relationship by examining an organizational chart and recall the urgency of the recipient's responses to previous messages from the same sender. To this it might add information gathered by watching the user by video camera or scrutinizing his or her calendar. At the system's heart is a Bayesian statistical model—capable of evaluating hundreds of user-related factors linked by probabilities, causes and effects in a vast web of contingent outcomes—that infers the likelihood that a given decision on the software's part will lead to the user's desired outcome. The ultimate goal is to judge when the user can safely be interrupted, with what kind of message, and via which device.

Horvitz expects that such capabilities—to be built into coming generations of Microsoft's Office software—will help workers become more efficient by freeing them from low-priority distractions such as spam e-mail, or scheduling meetings automatically, without the usual rounds of phone tag. That will be a big step forward from Clippy, the animated paper clip that first appeared as an office assistant in Microsoft Office 97, marking Microsoft's first commercial deployment of Bayesian models. Horvitz says his group learned from Clippy and other intelligent assistants—which were derided as annoyingly intrusive—that A.I.-powered assistants need to be much more sensitive to the user's context, environment and goals. The less they know about a user, Horvitz notes, the fewer assumptions they should make about his or her needs, to avoid distracting the person with unnecessary or even misguided suggestions.

Another ambitious project in Horvitz's group aims to achieve better speech recognition. His team is building DeepListener, a program that assembles clues from auditory and visual sensors to clarify the ambiguities in human speech that trip up conventional programs. For instance, by noticing whether a user's eyes are focused on the computer screen or elsewhere, DeepListener can decide whether a spoken phrase is directed at the system or simply part of a human conversation *(see "Natural Language Processing,"* TR *January/February 2001)*.

In a controlled environment, the system turns in an impressive performance. When ambient noise makes recognition harder, DeepListener tends to freeze up or make wild guesses. But Horvitz's group is developing algorithms that will enable the software to behave more as hard-of-hearing humans do—for example, by asking users to repeat or clarify phrases, or providing a set of possible meanings and asking for a choice, or sampling homonyms in search of a close fit. But this work veers toward the very limits of A.I. "Twenty-five years from now," Horvitz acknowledges, "speech recognition will still be a problem."

STILL SEARCHING FOR THE MIND

Whether it takes 25 years or 50 to achieve perfect speech recognition, such practical goals are still far closer than understanding, let alone replicating, human consciousness. And embracing them has allowed significant progress—with far more to come. In corporate research departments and university programs alike, artificial-intelligence researchers are finding new ways to automate labor-saving devices, analyze information about our physical world or make sense of the vast reserves of information entombed in libraries and databases. These range from the interactive Web- and computer-based training courses devised by Cognitive Arts, a company founded by Roger Schank, the former head of the artificial-intelligence program at Yale University, to a system developed by the Centre for Marine and Petroleum Technology, a European petroleum company consortium, to analyze the results of oil well capacity tests.

But considering how dramatic a departure so much of this work is from traditional A.I., it is unsurprising that some researchers have their reservations about the field's newly pragmatic bent.

Today's artificial-intelligence practitioners "seem to be much more interested in building applications that can be sold, instead of machines that can understand stories," complains Marvin Minsky of the MIT Media Lab, who as much as anyone alive can lay claim to the title of A.I.'s "grand old man." Minsky wonders if the absence of a "big win" for artificial intelligence—what mapping the human genome has meant for biology or the Manhattan Project for physics—has been too discouraging, which in turn saddens him. "The field attracts not as many good people as before."

Some vow to keep up the fight. "I've never failed to recognize in my own work a search for the secret of human consciousness," says Douglas R. Hofstadter, whose 1979 book *Gödel, Escher, Bach: An Eternal Golden Braid* was constructed as an extended "fugue on minds and machines" and who evinces little patience with those who would reduce A.I. to a subfield of advanced engineering. "The field is founded on the idea that if intelligence is created on the computer, it will automatically be the same kind of consciousness that humans have," says Hofstadter, currently director of the Center for Research on Concepts and Cognition at Indiana University. "For me it has always been a search for thinking." Hofstadter warns researchers against losing sight of this quest.

The elusiveness of the goal, Hofstadter and others stress, does not mean that it is unattainable. "We should get used to the fact that some of these problems are very big," says Stork, the editor of *HAL's Legacy*. "We won't have HAL in my lifetime, or my children's."

But even as artificial-intelligence researchers work toward the big win, many have turned their attention to more practical pursuits, giving us software that can sort our mail, find that one-in-a-billion Web page or help rescue workers pull us from the wreckage of an accident or terrorist attack. And their successes may be what will keep A.I. alive until it's truly time to rekindle the quest for an understanding of consciousness. TR

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MERCK'S MISSION: AN AIDS VACCINE

By Jon Cohen

Twenty years after the AIDS epidemic surfaced, pharmaceutical giant Merck is throwing its R&D muscle into an AIDS vaccine. But will it be enough?

Emilio Emini, a bear of a man, spreads his arms wide and slaps one hand on either side of a 20-ton globe that rotates in a fountain in front of the Merck Research Laboratories in West Point, PA. Etched onto the globe are the seven continents, with stars marking the 10 satellite Merck research labs. "You can stop it," says Emini, muscling the globe to a halt. He then rotates it himself, showing off the stars in the United States, Canada, Europe and Japan; Africa sinks into the water and then reemerges.

Emini, who headed the Merck R&D team that in 1996 brought to market what has become a bestselling "protease inhibitor" drug against HIV, now runs the company's large AIDS vaccine research project. The effort's unprecedented scope and analytical rigor have invigorated the world of research aimed at shackling HIV with a vaccine, which could ultimately provide a far more powerful weapon against AIDS than drugs.

Global power: Merck's Emilio Emini has the weight of a multinational pharmaceutical giant behind him in his fight against AIDS.

PHOTOGRAPH BY BOB CIMMINO/MERCK

While cocktails of anti-HIV drugs have lengthened many lives, no one has been cured, and patients must take several different kinds of pills, on a strict schedule, several times each day. The drugs also are costly, toxic, tricky to prescribe and, if improperly used, can lead to drug-resistant strains of HIV. Compare that to a vaccine, which after a few shots could protect someone from AIDS for years or decades.

It's far too early to know whether the Merck effort will have any success in stopping HIV and rescuing sub-Saharan Africa and other regions that are drowning in the disease unleashed by the virus, which now has infected 40 million people and killed 25 million more. But the effort signals that big pharmaceutical companies at long last are devoting serious resources to the search for a vaccine, the best hope the world has for ending this epidemic.

Since 1984, the year scientists proved that HIV causes AIDS, drug and biotech companies have tested 50 different anti-HIV vaccines in humans *(see "The AIDS Vaccine Pipeline," p. 65)*. Only two of those vaccines, however, have made it beyond the first phase in the three-stage human-testing process, and both have had mediocre performances. Indeed, many researchers expect them to fail when put to real-world tests. Part of the problem, critics say, is that the pharmaceutical industry's investment in such human studies and the experiments leading up to them has been inadequate. Drug companies prefer to invest in treatments, which are much more profitable than vaccines. Only three big pharmaceutical companies other than Merck—Aventis Pasteur, American Home Products and GlaxoSmithKline—even make vaccines. Although each has an AIDS vaccine program, with Aventis Pasteur's by far the most advanced, all have much smaller programs than Merck's; and all, unlike Merck, rely heavily on government funding to stay afloat. As a result, cash-strapped biotech firms, many of which have no experience making vaccines, have dominated the field, often pushing forward dubious strategies and hyping small advances in desperate attempts to raise funds from private investors.

Emini's AIDS vaccine project not only enjoys the full-fledged, deep-pocketed support of a major pharmaceutical company, it also has an unusually strong scientific foundation. Last year, Merck revealed details of an ambitious four-year monkey study more extensive and systematic than any researchers had seen before. In the study, Emini's team used hundreds of monkeys to analyze and compare several different vaccine approaches, and used the results to choose a novel vaccine strategy, which Merck now is starting to test in humans and hopes to take into large-scale trials in conjunction with the National Institutes of Health.

These developments have injected a huge dose of hope into a field rife with disappointment. "Their program is world class," says Caltech president David Baltimore, a Nobel laureate who heads NIH's AIDS Vaccine Research Committee. Baltimore compares Merck to Aventis Pasteur, which now has a vaccine that's poised to enter the final stage of human testing. "The difference between Merck and Aventis Pasteur is the depth of the basic research. Aventis's commitment has been long and strong, but not deep. Merck got strong animal data before they moved into humans. I give Aventis tremendous credit for what they've done, but I think they've been potentially passed by Merck."

But despite the optimism it has generated, Merck's AIDS vaccine effort raises some troubling questions. Why did Merck take on AIDS with such ferocity now and not 10 years ago? Why has an AIDS vaccine remained a stepchild, without the intense scrutiny and sense of urgency that have surrounded anti-HIV drugs? Will Merck's rigorous program prod others to ramp up their efforts? Is the search for an AIDS vaccine, even with Merck's contribution, as ambitious as it should be?

DETOURS AND DEAD ENDS

On April 23, 1984, secretary of health and human services Margaret Heckler held a press conference in which she announced that scientists from the National Institutes of Health had discovered that HIV was the probable cause of AIDS, and she made this infamous prediction: "We hope to have…a vaccine ready for testing in approximately two years."

Many have made a fool of Heckler for this statement, which now sounds so naively optimistic. But Heckler, like a member of the chorus in a Greek drama, unwittingly augured the future with tragic accuracy. The first AIDS vaccine tests did take place in 1986, yet the field has progressed in such a lumbering, haphazard fashion that 16 years later researchers still cannot draw firm conclusions about the worth or worthlessness of any approach.

Merck's own program met its share of dead ends. With Emini at the helm, the company began working on AIDS vaccine R&D in 1986. That same year, the company brought to market a hepatitis B vaccine that exploited the wonders of genetic engineering, ushering in a new era for vaccinology. The stunning success with the hepatitis B vaccine led Merck and many others in the field to investigate a similar strategy for an HIV vaccine. But they soon realized that they had underestimated their foe. Like the Hydra, which sprouted two more heads in place of every one that Hercules clubbed off, HIV dodges immune attack by constantly sprouting mutations. "HIV is able to grow in the face of the best immune response the body can make," emphasizes Caltech's Baltimore.

Traditional vaccines exploit an irony of nature: the bug that causes a disease can, when given in a modified form, safely prevent the disease by teaching the immune system to identify and cripple it on sight. The genetically engineered hepatitis B vaccine went one better, priming the body to make antibodies by using nothing more than a protein that studs the surface of the virus, reducing side effects and leaving no room for infectious viruses to accidentally make it into the vaccine. But when researchers tried the same technique with AIDS, using a genetically engineered version of the surface protein that studs HIV, the result was as ineffective as cutting off one of Hydra's heads. (One company, VaxGen of Brisbane, CA, has doggedly stuck with this approach, and its vaccine in 1998 became the first to enter full-scale efficacy trials in humans, which are still under way.)

By 1993, Merck had all but scuttled its AIDS vaccine project and shifted Emini to the head of a team developing a protease inhibitor against HIV. (Protease inhibitors don't prevent infection but quell the ability of an infected person's cells to make new viruses, slowing—and for a time even reversing—the disease.) In 1997, one year after Merck marketed the bestselling protease inhibitor Crixivan, Emini turned back to the AIDS vaccine project. In a remarkable flip-flop, Merck quietly began a new program that completely ignores HIV's surface proteins and antibodies.

Framing the issue: NIH's Anthony Fauci says that, in an arena as complex as AIDS vaccine research, it's not science alone that drives progress.

PHOTOGRAPH BY WALTER SMITH

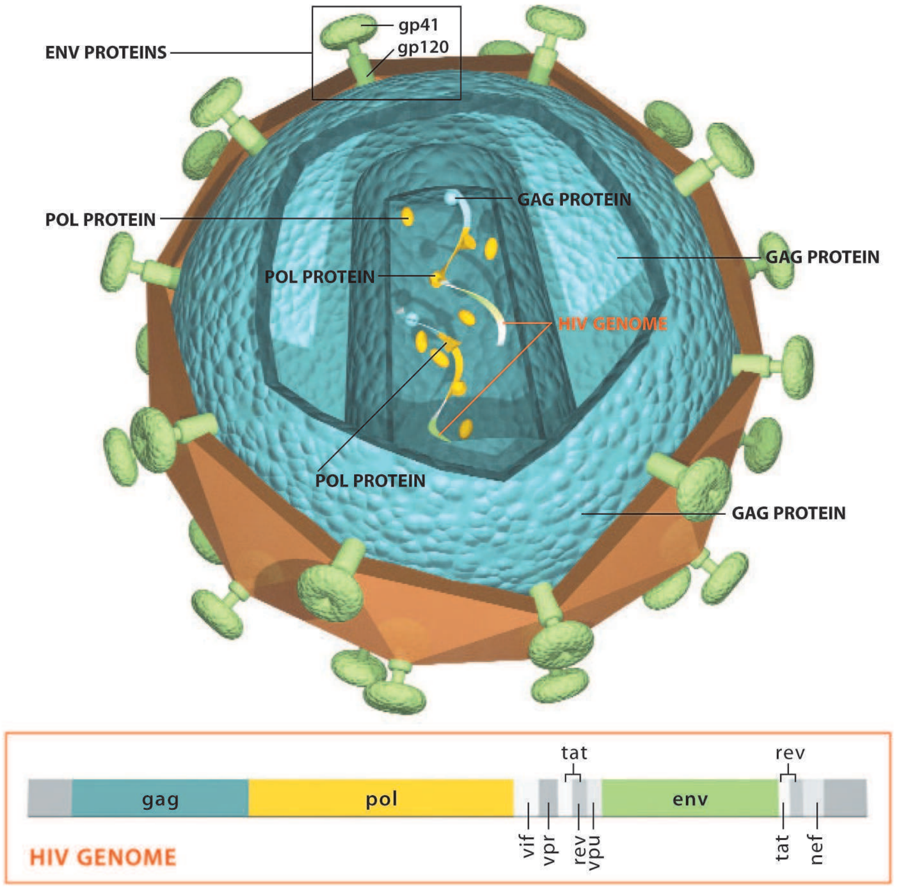
"Now it seems like a reasonable thing to do," Emini says. "Will it seem like a reasonable thing to do two years from now? I'll let you know two years from now."

And Merck's reentry into the field with an intensive, methodical new program has buoyed spirits tremendously. Researchers are excited because Merck makes a habit of backing its scientists—and has ample cash with which to back them. In 2000, Merck grossed $40 billion and funneled nearly one-third of its $6.8 billion net back into R&D. In short, if Merck wants something, it does not need help from the government or philanthropies. It just takes out its checkbook.

Consider how Merck responded to Emini's decision to build the new AIDS vaccine program around studies in monkeys, which are in short supply and notoriously expensive. Ordinarily a company that does such experiments relies on academic collaborators who have access to government-funded primate research centers, or it hires a private firm that raises the animals. Merck simply bought its own monkey-breeding colony in 1999 and since has supplemented it with hundreds of additional animals. Anthony Fauci, director of NIH's largest AIDS branch, the National Institute of Allergy and Infectious Diseases, notes that Merck has a long history of converting basic research insights into products. "Merck's record speaks for itself," says Fauci.

HIV Anatomy

HIV has just a handful of genes and proteins that can form the basis for a vaccine. Researchers have incorporated these molecules individually or in combination in the vaccines listed on the next page.



JOHN MACNEILL

TURNING POINT?

Emini and his right-hand man, John Shiver, first unveiled Merck's monkey data to their scientific colleagues at a prestigious AIDS vaccine meeting in spring 2001 in the ski town of Keystone, CO. Merck came to the meeting in full force, sending 30 of its scientists, accounting for nearly 10 percent of the total participants. No other company even *has* 30 scientists devoted to AIDS vaccine R&D. When Shiver and Emini showed a slide at the end of their presentations that listed nearly 50 senior investigators with their own teams working on the project, there were audible gasps from the audience. Merck towered over the other companies with its mountain of new scientific data.

When it came time for Shiver to speak, he showed a head-to-head comparison of five different vaccines in 21 monkey experiments. Asian monkeys develop an AIDS-like disease when infected with simian immunodeficiency virus, a monkey cousin of HIV, or with a laboratory-made hybrid virus that combines the monkey virus and HIV. Researchers can vaccinate monkeys and then challenge their immune systems with an injection of either of the two viruses to test the worth of the vaccine. Merck created its test vaccines by stitching a gene that codes for a protein from the interior of the monkey AIDS virus into five different "vectors" that carry the gene into the body. Three of the vectors were simply circular pieces of bacterial DNA, or "naked DNA"; the other two were harmless viruses commonly used in vaccines.

Merck's best results in these monkeys closely resembled those seen by some of the academic researchers at the meeting: vaccinated monkeys became infected when challenged with the hybrid virus. But unlike unvaccinated animals used as controls, the vaccinated monkeys remained healthy. The researchers linked their protection not to antibodies but to a less famous contingent of the immune system, killer cells. Antibodies and killer cells work in concert. Antibodies glom onto invaders and prevent them from infecting cells; killer cells clean up, targeting and eliminating cells the invader manages to infect. Merck's research showed an edge over other groups' work in such subtle parameters as killer-cell production and levels of the hybrid AIDS virus found in the protected animals. More importantly, Merck had moved quickly to begin testing the most promising vaccines in humans, a feat that none of the academics could match.

Everyone acknowledges that the monkey results may not translate into humans. Ronald Desrosiers, head of Harvard University's primate center and a pioneering AIDS vaccine researcher, emphasizes that researchers still are guessing whether a vaccine needs to crank up production of killer cells, antibodies, a combination of these responses, or some other immunologic warriors. "Believe it or not, we have no frickin' clue what one needs for an effective immune response," Desrosiers says.

THE YOUNG INNOVATORS WHO ARE CREATING THE FUTURE

TR100

WHO WILL BE NEXT?

NATALIE JEREMIJENKO

DIRECTOR OF THE YALE UNIVERSITY ENGINEERING DESIGN LAB

2000 TR100 HONOREE

AGENDA

2002 TR100 SYMPOSIUM AND AWARDS CEREMONY

8:00 - 8:30 **Continental Breakfast**

8:45 - 9:30 **Morning Keynote**

CLAYTON CHRISTENSEN
PROFESSOR OF BUSINESS ADMINISTRATION,
HARVARD BUSINESS SCHOOL
AUTHOR, *THE INNOVATOR'S DILEMMA*

This session will provide you with a preview of what's new since *The Innovator's Dilemma*. The management of innovation today is where the quality movement was 30 years ago. It's time to close the gap.

9:45 - 11:00 **Panel Discussion—Transformative Technologies**

SPEAKERS TBD

This panel will be representative of the scope of the TR100. CEO panelists from our core segments—pharmaceuticals/biotech, computers/communications, transportation and energy—will discuss the power and relevance of these key technologies as engines of economic growth.

11:00 - 11:15 **Break**

11:15 - 12:15 **Security, Privacy and Technology**

DAVID BOIES, FOUNDING PARTNER,
BOIES, SCHILLER AND FLEXNER

KENNETH STARR, PARTNER, KIRKLAND AND ELLIS AND ADJUNCT PROFESSOR, NEW YORK UNIVERSITY SCHOOL OF LAW

NADINE STROSSEN, PRESIDENT, ACLU

Few topics are as integral to the success of innovation in the global economy as security and privacy. New technologies allow individuals, corporations and government entities to monitor, track and identify employees, customers and the general public. *Technology Review* will provide a forum to discuss this most important topic.

12:15 - 1:30 **Lunch**

1:45 - 3:00 **Concurrent Afternoon Conversations**

These sessions will provide an in-depth perspective on the three industries that will have the most pronounced benefit from transformative technologies.

Session #1 **Beyond Pervasive Computing**

MODERATED BY: ROBERT BUDERI, EDITOR AT LARGE,
TECHNOLOGY REVIEW AND
AUTHOR, *ENGINES OF TOMORROW* AND
THE INVENTION THAT CHANGED THE WORLD

DAVID TENNENHOUSE, VICE PRESIDENT AND CORPORATE TECHNOLOGY GROUP DIRECTOR, RESEARCH, INTEL CORPORATION

RICHARD RASHID, SENIOR VICE PRESIDENT,
MICROSOFT RESEARCH

RODNEY A. BROOKS, FUJITSU PROFESSOR OF COMPUTER SCIENCE AND ENGINEERING,
DIRECTOR OF THE ARTIFICIAL INTELLIGENCE LABORATORY AND CO-DIRECTOR OF PROJECT OXYGEN, MIT

Pervasive computing means different things to different people. We are moving into a world of increased connectivity, where everything and everyone is highly networked, and computing services and applications are available anytime/anywhere, wired and wireless. This connectivity is also called grid computing.

Leading computer scientists are promoting a new idea that goes a step beyond: proactive, or attentive, computing. But for computing to really be productive anytime/anywhere, it must not just respond to users but anticipate their needs through agents, data mining, sense-making and other software applications.

Session #2 **Personalized Medicine**

REBECCA HENDERSON, EASTMAN KODAK LFM PROFESSOR, MIT SLOAN SCHOOL

DARLENE SOLOMAN, DIRECTOR OF THE LIFE SCIENCE TECHNOLOGIES LABORATORY, AGILENT TECHNOLOGIES

KARI STEFANSSON, PRESIDENT AND CHIEF EXECUTIVE OFFICER, deCODE GENETICS

We've deciphered the human genome and moved into the study of the individual proteins that the genes code for. Such advances anticipate the day when drugs are not only targeted at molecular workings or specific diseases but tailor-made for each individual's genetic makeup. The personalized-medicine market is experiencing dynamic growth. Over $700 million has been invested in proteomics in the past year.

Session #3 **Energy and Transportation—Supply, Demand and the Technologies to Solve Key Bottlenecks**

MODERATED BY: RICHARD LESTER, DIRECTOR, INDUSTRIAL PERFORMANCE CENTER AND
PROFESSOR OF NUCLEAR ENGINEERING, MIT

FIROZ RASUL, CHAIRMAN AND CHIEF EXECUTIVE OFFICER, BALLARD POWER SYSTEMS

KURT YEAGER, PRESIDENT AND CHIEF EXECUTIVE OFFICER, ELECTRIC POWER RESEARCH INSTITUTE, INC.

BJORN STIGSON, PRESIDENT,
WORLD BUSINESS COUNCIL FOR SUSTAINABLE DEVELOPMENT

Few subjects have so captivated the general business community as the perceived power shortages in California. The Enron collapse, deregulation, demand and supply bottlenecks created havoc on both city streets and Wall Street. Americans spent nearly $600 billion on energy in 1999, and with developing nations expected to consume nearly the same amount of oil as industrialized nations, world energy consumption is expected to surge by 59% by 2020. New technologies and new implementations of existing technologies can render many of these challenges obsolete.

3:00 - 3:15 **Break**

3:15 - 4:30 **Introducing the TR100**

MODERATED BY: BOB METCALFE, INVENTOR OF ETHERNET AND FOUNDER OF 3COM CORPORATION

Bob Metcalfe will moderate a panel discussion with select TR100 alumni who vividly illustrate the power and future of transformative technologies.

4:45 - 5:15 **Announcement of the Innovator of the Year**

7:30 - 10:00 **Black-Tie Gala at the Hyatt Regency**
Cambridge, Massachusetts

Please note: Agenda subject to change. The sponsors and management of *Technology Review* reserve the right to make any necessary changes to this program. Every effort will be made to keep presentations and speakers as represented. However, unforeseen circumstances may result in the substitution of a presentation topic or speaker. Technology Review, Inc. reserves the right to use photographs or video of any TR100 attendee for future promotions.

REGISTRATION

2002 TR100 SYMPOSIUM AND AWARDS CEREMONY

MAY 23, 2002

SYMPOSIUM
Kresge Auditorium on the
MIT Campus
Cambridge, Massachusetts

AWARDS CEREMONY
Hyatt Regency
Cambridge, Massachusetts

4 WAYS TO REGISTER!

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Cancellations and Substitutions

If you must cancel for any reason, we will need written notice of cancellation by Wednesday, May 1, 2002. Your registration will be refunded less a $100 processing fee. Cancellations after Wednesday, May 1, 2002, are non-refundable. You may transfer your registration to another person at any time by providing written authorization. Please send all cancellation and transfer notices to *Technology Review*, Attn: Sharon Morani, 1 Main Street, 7th floor, Cambridge, MA 02142. They can also be sent via fax to (617) 475-8042.

Press Information or Press Registration

For information on registering as a member of the press for *Technology Review*'s TR100 or to request press releases for this conference, please email Kristen Collins at Kristen@kmcpartners.com.

Hotel Accommodations

Technology Review has secured a special group rate at:
Hyatt Regency, Cambridge
575 Memorial Drive, Cambridge, MA 02139
Phone: (617) 492-1234
www.hyatt.com

TR100 attendees will receive the special room rate of $179 for a single or double room. Rooms are available from Wednesday, May 22, through the evening of Friday, May 24, 2002.

To make your reservations, please call the hotel directly at (617) 492-1234 and reference *Technology Review* 2002. You can also make your reservations online at www.hyatt.com.

To secure the discounted rate, all reservations must be made directly with the hotel by April 22, 2002. Reservations made after the cut-off date will be made on a space availability basis. For more information visit the Hyatt Web site at www.hyatt.com.

REGISTRATION FORM

ALL INFORMATION REQUIRED

☐ Please register me for the general session only for $1,195.

☐ Please register me for the general session AND gala awards ceremony at the Hyatt Regency for $1,495.

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Another huge problem is that different labs often test their vaccines against different challenge viruses, each of which has a different potency. "You can get basically any result you want based on the challenge virus you use," says Desrosiers, who believes that the hybrid AIDS virus used in Merck's tests is relatively easy to thwart. "Nothing against Merck, but it's going to be damn tough to protect against viruses in the field," he says, where much more robust strains of HIV run rampant.

Despite the caveats, Merck is going forward with extensive human studies to evaluate a strategy combining two different vaccines—the combination that best stimulated killer-cell production in monkey studies. In all, a few hundred volunteers at 50 different university medical centers and private clinics will receive Merck's naked-DNA vaccine followed by booster shots that use a common-cold virus as a vector. If the human tests prove that the vaccine strategy is both safe and consistent in stimulating strong killer-cell responses, the one-two punch may move into a full-scale efficacy trial in thousands of people to assess whether it truly is the biological better of HIV. Merck refuses to speculate when such trials might start, but Emini allows that even in the best of all possible worlds, his team will not have evidence that its strategy works for at least five more years.

MARKET FAILURE

Why has it taken so long to get to this exciting—if uncertain—moment? Part of the answer lies in the economics of vaccines. There's a reason why the big pharmaceutical companies are reluctant to get into the vaccine business: it's notoriously unprofitable. The most recently available figures estimate that in 1999, the worldwide sales for all licensed vaccines totaled between \$4.3 billion (according to GlaxoSmithKline) and \$6 billion (according to Theta Reports, which specializes in health-care market research). Merck's bestselling product that year, a cholesterol-lowering drug, grossed \$4.5 billion in sales. One bestselling drug, that is, grossed roughly the same amount of money as the entire worldwide vaccine market. Vaccines, which go into healthy people, including children with parents who aggressively sue if their offspring are injured, also have a much higher liability risk than drugs.

For these reasons, the mid-1990s saw a "market failure": the big pharmaceutical firms simply were not spending a lot of money on pursuing an AIDS vaccine. To address the failure, academic and government researchers banded together and in 1996 formed the nonprofit International AIDS Vaccine Initiative. Billing itself as a "virtual industry," the organization set up product development teams that match scientists from wealthy and poor countries with biotech firms in an effort to produce affordable vaccines. NIH revamped its program to work more closely with industry, building its own Vaccine Research Center, which can manufacture experimental products. European researchers established an AIDS vaccine consortium called EuroVac. And AIDS activists, who long have focused on treatment issues and all but ignored vaccines, started the AIDS Vaccine Advocacy Coalition, which has chastised the pharmaceutical industry for not doing more.

The AIDS Vaccine Pipeline

ORGANIZATION	VACCINE	DEVELOPMENT STAGE
VaxGen (Brisbane, CA)	Gp120 protein	Phase III
Aventis Pasteur (Lyon, France)	Various HIV genes and gene fragments in viral vector	Phase II
Merck (West Point, PA)	Gag gene in naked DNA; gag gene in viral vector	Phase I
Cobra Therapeutics (Keele, U.K.) and **Impfstoffwerke Dessau-Tornau** (Rosslau, Germany)	Small fragments of gag, pol and nef genes in naked DNA; the same fragments in viral vector	Phase I
German Research Center for Biotechnology (Braunschweig, Germany)	Tat protein	Phase I
Aventis Pasteur	Small synthetic HIV protein fragments	Phase I
AlphaVax (Research Triangle Park, NC)	Gag gene in viral vector	Preclinical
Therion Biologics (Cambridge, MA)	Env and pol genes in viral vector	Preclinical
Chiron (Emeryville, CA)	Gag gene in naked DNA attached to polymer microspheres; gp120 protein	Preclinical
GlaxoSmithKline (Uxbridge, U.K.)	Gp120 protein; nef-tat fusion protein	Preclinical
Protein Sciences (Meriden, CT)	Gag protein	Preclinical
Virax Holdings (Kew, Australia), **Institute of Drug Technology** (Bornia, Australia) and **University of New South Wales** (Sydney, Australia)	Various HIV genes in naked DNA; gag and pol genes in viral vector	Preclinical
EuroVac (European consortium)	Gag, pol, env and nef genes in viral vector; env protein	Preclinical
Wyeth Lederle Vaccines (Collegeville, PA) and **Yale University** (New Haven, CT)	Various HIV genes in naked DNA; small engineered HIV protein fragment	Preclinical
Wyeth Lederle Vaccines	Env and gag genes in viral vector	Preclinical
Institute of Human Virology (Baltimore, MD)	Env and gag genes in viral vector	Preclinical
Advanced BioScience Laboratories (Kensington, MD)	Env and tat genes in naked DNA	Preclinical
Emory University (Atlanta, GA)	Gag, pol, vif, vpx, vpr, env, tat and rev genes in naked DNA; gag, pol and env genes in viral vector	Preclinical

Straight talker: Harvard University's Ronald Desrosiers believes that, despite recent advances, researchers still have a lot to learn about AIDS vaccines.

PHOTOGRAPH BY FURNALD/GRAY

All of which has increased the pressure on companies like Merck to put their weight behind the push for a vaccine, but none of which has significantly altered the financial risks. Merck CEO Ray Gilmartin has a *Field of Dreams* attitude about this uncertainty, pshawing the idea that the dodgy marketplace for an AIDS vaccine has influenced his company's efforts. "There's a commitment to say that if the science is there and it's possible to do, we're going to do it," he says. "We haven't run any numbers on this, either. I think there's the implicit belief that if you come up with a breakthrough drug and you're serving a large unmet need, the commercial success takes care of itself."

Gilmartin guarantees that if a Merck AIDS vaccine ever exists, the company will, from day one, sell it at a steep discount to poor countries. "Offering vaccines at far lower prices in the developing world is a way of generating volume that otherwise would not be there," says Gilmartin. "So everyone really benefits." Gilmartin's cheery view of the marketplace makes sense—up to a point. Merck surely has moved forward because the science is more "there" than ever before. Not only has the field recognized the difficulty of making an antibody-based vaccine, the scientific tools have advanced. A few years ago, for example, hardly any primate researchers could precisely measure killer cells or levels of virus found in the blood of monkeys. Now, these tests are the cornerstone of Merck's program.

Clearly, though, there are more forces at work than just scientific advances. "In an arena as complex as this, there's never just one thing," says NIH's Fauci. "It's not waking up and going, 'Ah, now we have enough science.' It's also an ever growing awareness of the monumental scope of this epidemic." But as the urgency has mounted, researchers also have lowered their expectations about what an AIDS vaccine must do. Rather than aiming for complete protection from HIV infection—the original target—they would now be happy if their preparations mimicked the monkey experiments and prevented or delayed disease. A vaccine that fails to block infection—and might have been discarded 10 years ago—now would be widely heralded if it could just thwart AIDS.

Ed Scolnick, the head of Merck Research Labs and Emini's boss, sees another potential market for AIDS vaccines: boosting the immune systems of people who are already infected. Merck already has started early trials of AIDS vaccines as treatments, combining this theoretically nontoxic immune-boosting strategy with the drugs that attack the virus directly. Although it will take a few years before researchers can determine whether this "postinfection" vaccine can help stymie HIV's assault on the immune system, the mere fact that Merck is attempting this approach signals a huge shift in thinking—one that could pay off financially as well as medically. "Maybe we'll make more economic return on that than the preventive side," says Scolnick.

Two other large vaccine makers, GlaxoSmithKline and American Home Products (through its Wyeth Lederle Vaccines division), have taken notice of the changing landscape, moving several new vaccine candidates toward clinical trials since Merck's human tests began. Aventis Pasteur, with help from the U.S. military, NIH and the French government, hopes to soon launch full-scale efficacy trials of its vaccine, which stitches HIV genes into a harmless bird virus called canarypox. And by the end of 2002, VaxGen should complete its full-scale efficacy trials—which involve nearly 8,000 people in North America, Europe and Thailand—determining once and for all whether a genetically engineered protein of HIV can bolster the immune system against the virus. Something of an AIDS vaccine renaissance, then, is under way. "It's night and day between now and five years ago," says David Baltimore.

Microsoft chairman Bill Gates, whose charitable foundation will give the International AIDS Vaccine Initiative more than $126 million over the next five years, feels it's been a long time coming. "Come on, it's 2001 and we don't have an AIDS vaccine," he said in an interview last year. Gates applauds Merck's involvement, but he believes that even the company's evaluation in monkeys of five different vaccine candidates falls short of what's needed, and he is frustrated by the absence of a study that would carefully compare the performance of 50 or even 100 vaccines. "I'm not a biologist, I'm a computer scientist, and so the idea that you can be very systematic about things and measure things, in the world of computer science you almost take that for granted," says Gates. "In biology, that's the hard part."

MERCK 002

Sean, a 33-year-old gay man, is one of the participants in Merck 002, the first human trial of the company's AIDS vaccine. On a morning in April 2001, a nurse at Massachusetts General Hospital (Harvard Medical School's largest teaching hospital) fills two test tubes with his blood, which she will then send to Merck for analysis. Like others in the study, Sean, who asked that his last name not be used, classifies himself as low risk for becoming infected and says he has joined the trial for altruistic reasons. Like all initial human trials of vaccines, this one is not designed to test the preparation's effectiveness. But the 17 blood samples that Sean will give during Merck 002 will help establish whether the vaccine is safe and how it affects the immune system. "Maybe this isn't the be-all and end-all of it, but hopefully it will lead to something they don't know now, and it will give them a better starting point for the next one," he says. "The epidemic didn't just happen, and it's not going to just go away."

These words are music to Emini's ears. Emini well understands that the excitement about Merck directly ties into the bleak reality that AIDS vaccine researchers have become accustomed to—a diet of confusion, dashed hopes and promising leads that go nowhere. But he knows, too, that every AIDS vaccine developer hoping to reach the marketplace likely will meet up with the scientific, social and ethical equivalent of Hydras, man-eating horses and birds that can use their feathers as arrows. "Understand, two years from now, we may be working on plan B," says Emini. "I hope we have a plan B. I just don't know."

Emini shrugs his wide shoulders when asked whether he's beginning to feel competition from the intensified efforts of other companies, NIH, the International AIDS Vaccine Initiative and EuroVac. "The competition isn't anyone else in this field," he says. "It's that virus." And Emini cringes at the congratulations he has been receiving from people who have learned the details of Merck's program. "Even though they don't overtly say it, you can hear that there's hope there," he says. "And you say, 'Well, yeah, thank you, but I don't know if it's going to work.' I keep on saying, 'If all this works, God willing.' I don't say it because I'm superstitious. I mean it. I certainly don't have the answers here." TR

By Nick Montfort

ILLUSTRATIONS BY JOHN CRAIG

FROM PLAYSTATION TO PC

Advances in video games and other technologies feed off one another, pushing computing further, faster.


REALNEAT
FOUR ROSES
PLANTERS
PEANUTS

The school bell rings, and teenagers flood the hallways, heading for lockers, the lunchroom, their next classes. Many pull out Cybikos—popular handheld devices that are a combination personal digital assistant, wireless messenger and game machine. Some students update their calendars with the latest homework assignments, but others check on their Cy-Bs. While the kids have been studying math, history and science, these colorful cartoon creatures have been eating, working, playing together, paying taxes—even breeding—in CyLandia, their virtual game world. The game's goal is to raise happy, productive Cy-Bs that live long and prosper; players accomplish this by training the Cy-Bs, sending them over a local wireless network to visit other players' Cy-Bs to improve their social skills, and helping them find jobs.

This is the new face of video gaming—mobile, networked, interactive and remarkably lifelike. More to the point for society at large, its rapid adoption by a generation of young computer users may herald aspects of the future of computing in general—from PCs, to personal digital assistants like the Palm, to cell phones. You may soon be able to take a virtual walk through your computer's contents, interact with scores of people in real time and send artificially intelligent agents out to do your bidding; and if you do, you will owe a word of thanks to game devices like Cybikos. Indeed, games have long played a special role in driving computing. "The segment of software that has pushed hardware development most is games," says game developer Bernard Yee, former director of programming at Sony Online Entertainment.

This influence seems to be accelerating. The 2000 U.S. census found that 54 million American households currently have computers—and Yee says that gaming is now "arguably the number one use" of those machines. "It's reported as the number two use, behind word processing," he says. "But people don't like to admit that they play games." Boston-based consulting firm IDG estimates that North Americans will own over 72 million dedicated game consoles by 2004—be they Sony PlayStations, Nintendo GameCubes or Microsoft's new Xboxes. All this game play is likely to influence younger users' expectations for their other computing experiences. Real-time networking, 3-D graphics, interactive interfaces, artificial-intelligence systems and the computerized home of the future will all reflect the synergy between gaming and other areas of computing. "The next generation of people that are going to be using [computers] are much more familiar with this sort of stuff and are that much more comfortable with it," says Steven Drucker, a researcher in the Next Media group at Microsoft Research. And, he notes, they will likely demand the same technologies and user experiences from other computing devices as well.

In short, games point to where computing is headed.

Graphic Roots

Gaming and other areas of computing—business, academic research, the Internet and more—have had a symbiotic relationship since the early days of video games, with hardware and software developments frequently crossing from one field to another and driving the evolution of both.

Home game consoles, introduced in the early 1970s, preceded the home computer revolution of the 1980s. In fact, devices like the Magnavox Odyssey *(see "Video Game Odyssey," p. 96)*, the first successful game console, and the blockbuster Atari 2600 VCS were computers that novices could easily set up and hook to their TVs. The idea of using a TV as a graphical display persisted in early home computers like the Atari 400 and 800, the Commodore 64 and the Apple II. Although the television didn't end up being a great computer display, it helped computers gain a foothold in the home. Meanwhile, the games played on these early systems made graphics and sound capabilities more common and therefore affordable, fast-forwarding the development of other uses of graphics, in areas like desktop publishing. "The first computer that many homes had was a game console," says Trip Hawkins, founder of leading game maker Electronic Arts and now CEO of another game company, 3DO. "The video game has gone a long way to demystify computer technology."

Because of its implications for both games and computing, graphics innovation has proceeded at a torrid pace. It was impressive enough when computers, which used to draw spaceships as triangles shooting square projectiles at star-shaped enemies, offered gamers in the mid-1990s a first-person view of underground mazes, simulating the experience of walking through a blocky environment. Now, game consoles have marched into photorealistic 3-D—rendering, in real time, scenes as complex as a nighttime street with rain and puddles reflecting neon lights, which two decades ago would have taken the most powerful computers weeks to generate. Although computer-generated people may not pass for movie images of real actors just yet, the skin tones and ever smoother features of these 3-D models are starting to cause double takes. "We may only be two generations away from graphics being good enough that it doesn't need to get any better," says Hawkins, one of many game industry veterans who name graphics as the most important video game technology, past and present. "The video game is driving the demand for graphic computing. You wouldn't even have graphics cards in PCs if it weren't for games."

"Five years from now, if you work on a PC that doesn't have tactile feedback, you'll think something's broken."

New graphics capabilities, however, suggest new applications. Graphical user interfaces are one area where the influence of games may soon play a major role. Microsoft Research's User Interface group, for example, has developed a new interface called Task Gallery to replace today's computer "desktop" *(see "The Next Computer Interface,"* TR *December 2001)*. In this 3-D virtual environment, users represent files and folders as pieces of art in a gallery. The 3-D space lets the researchers create visual relationships that help users remember where things have been stored.

George Robertson, who heads the Task Gallery group, notes that a key part of the effort is to create technologies that

let users readily find their way around a 3-D environment by, say, reproducing the perspective shifts they would experience navigating through connected rooms or negotiating turns. Video game developers are often ahead of his group. "The computer science researchers who work on 3-D navigation techniques pay close attention to what goes on in the gaming community," says Robertson. "There's a real symbiosis." He also believes that kids who are growing up playing games with 3-D environments will start demanding the same kind of interactivity from other computing applications. "The gaming community is definitely building a user population for us."

Computing with Feeling

While games have been influencing computer graphics for over 30 years, their effects on other technologies are just emerging. Haptics, which adds the sense of touch to computing through force feedback and other mechanisms built into input devices like mouses and joysticks, is one discipline making the transition from gaming to widespread adoption *(see "Touchy Subjects,"* TR *April 2001)*. "Haptic technology really made its first inroads in the gaming area," says Bruce Schena, chief technology officer of Immersion, a tactile-feedback device maker whose software led the way toward haptic interfaces for the PC. "Now we're seeing it show up more and more places, further into the mainstream."

Haptic interfaces were first available to the public in the arcade. Sega's 1986 OutRun was a driving game with a haptic twist: drive onto the shoulder, and the steering wheel trembled; crash, and it shook violently. But before 1996, PC games couldn't include force feedback because Microsoft Windows didn't have any way to output data to a controller. Then Immersion built a tool kit to help PC game makers add haptics to games, enabling players to feel various forces through a joystick, enhancing their experience and improving their control of simulated planes and cars. When Microsoft saw the first few games using the technology, it approached Immersion, and the two worked together to create tools to both help programmers and provide the necessary support in the operating system. Now, all main consumer haptic interfaces for the PC use the company's technology.

First marketed to PC gamers in a special mouse that was fixed to a pad, Immersion's technology has been integrated into the more ordinary-looking iFeel mouse from Logitech. Now haptic enhancements are available for Web sites and for Microsoft's Word and Excel, allowing users to "feel" when they mouse over a link or select a button on a toolbar.

While the ability to feel a Web link may not seem especially enticing, Immersion is exploring the use of the same basic interface to let PC users experience other sensations, such as temperature or complex textures—a feat that could have practical implications for, say, comparing the fabrics of clothes at online merchants. It has also worked with other companies to create "streaming tactile content" for the Web; objects that users can pivot and play with visually today will be touch enhanced in the near future. And Schena says tactile cues will go even farther. Immersion's research has shown that tactile cues become especially useful as visual interfaces get smaller and are used on the go, so it has developed haptic feedback technology for the "touch pads" used in laptop computers and is working on extending it to cell phones and touch screens for personal digital assistants. Says Schena, "We believe haptics will become an expected part of interfaces for all kinds of computing devices. Five years from now, for example, if you work on a PC that doesn't have tactile feedback, you'll think something's broken."

A.I. Gets Game

Beyond artificial touch comes artificial intelligence *(see "A.I. Reboots," p. 46)*, another field influenced by video games. This influence can be traced back at least to attempts to program computers to play chess better in the late 1950s. Microsoft's Drucker points out that A.I. techniques developed then have since become widely used commercially—for instance, in airline route planning. In the last decade, the availability of cheap computer power outside big labs, coupled with the hunger for ever more realistic games, has prompted game developers to

begin tackling artificial-intelligence questions once reserved primarily for academics. "The game industry is full of really bright, really well-read folks who are also pretty fearless," says A.I. researcher Bruce Blumberg, who heads the MIT Media Lab's Synthetic Characters group. "The combination means they're doing things that are really interesting."

Game developers have focused especially on finding ways to simulate the behaviors of humans and animals. A prime example is the award-winning game Black and White. Created by British game developer Peter Molyneux, the game offers a 3-D world in which the player takes the part of a god and trains a massive monster from birth, teaching it to either maim or assist villagers who call out for the player's help. The game quickly caught the attention of Michael Macedonia, chief scientist and technical director of the U.S. Army Simulation, Training and Instrumentation Command, who keeps a close watch on the video game industry, frequently borrowing techniques for military simulations. "When Peter was doing a demo one time, and he started beating the ape into submission—the ape gets bruises—I had to remind myself that this was a video game," says Macedonia.

Another case in point is Cybiko's CyLandia game. The tiny program runs a complex economical model of the Cy-Bs' world and can maintain several Cy-Bs with distinct personalities and social histories. The Cy-Bs also draw from software agent technology: the cartoon creatures perform most of their daily activities independently of their owners. "It's really unlike other A.I. products out there: it's thin, it's small, and it's robust," says Cybiko president Don Wisniewski. In fact, the A.I. proved so effective that the company incorporated it into the Cybiko operating system, which other device manufacturers have expressed interest in licensing.

All this is not a one-way street, of course. The Media Lab's Blumberg now regularly has his research group members attend game developer conferences—both to see what the gamers are up to and to share their own results. That interplay, he says, "is something that wouldn't have happened five years ago." The result is a synergy much like that found in the development of graphics, with each group furthering the work of the other.

The Virtual Society

Another force that could affect computing significantly is networked gaming, both wired and wireless. Online games are just hitting their stride, providing interaction on a scale no other system does, says Eric Zimmerman, cofounder of networked-game maker gameLab. The idea of connecting gamers in remote locations isn't new: in 1985 Lucasfilm created Habitat, an online gaming world that ultimately hosted thousands of users connecting from modem-linked Commodore 64s. Wider commercial success for this format has come more recently, most notably with Electronic Arts' Ultima Online in 1997 and Sony's EverQuest in 1999. Hordes of new games like these have opened their virtual worlds to players internationally since then. At any given moment, hundreds of thousands of gamers are meeting online in these 3-D fantasy worlds complete with their own species, economies and laws.

An online game system of this sort joins the graphically intensive demands of entertainment software with issues like scalability—maintaining high-quality service whether one person or tens of thousands of people are connected—that are more often associated with business systems. Yee, who led the development of EverQuest while at Sony, notes that although its system demands are not as strict as a financial network's, people invest a lot of time in developing characters, and what is stored on the EverQuest server has real value (EverQuest and Ultima Online characters often sell for more than $1,000 on eBay). "You need a high degree of reliability," he says.

Some of the technologies that went into building such systems are starting to make the transition to remote communication, education and videoconferencing. Microsoft's Drucker has worked on fashioning networked virtual worlds that let bone marrow transplant patients at the Fred Hutchinson Cancer Research Center in Seattle—in isolation due to their weakened immune systems—play games, chat, even share virtual presents with their families and friends. Other efforts aim to bring networked game technologies to bear on education. "Games are very compelling; they can be addictive," says Drucker. "And

if we can harness that addiction for education purposes, then you're going to have a wonderful synergy." In one Microsoft project, gamelike simulations are being used to help children with mild autism develop better social skills. And Drucker hopes teachers who know education but not programming may soon be able to use software originally designed to simplify the creation of massively multiplayer games to create networked virtual worlds to help demonstrate complicated concepts.

Videoconferencing applications are a bit further out, but Drucker and his Microsoft colleague Robertson say online worlds may influence the future of this field as well. A virtual conference using avatars or other graphical representations of participants would use less bandwidth than real-time video. Video interpretation technology could then be used to simulate participants' facial expressions. Virtual meetings could also solve the so-called gaze problem: a participant looking at her computer screen is always staring in the same direction, while in actual meetings, people tend to look at whoever is speaking. Avatars could be directed to look at the speaker automatically. "All of that gets you closer to face-to-face interactions," says Robertson.

The work in education and videoconferencing focuses mainly on fixed, wired networks. But wireless systems are also benefiting from game technology. Cybiko's personal digital assistants join a screen, tiny keyboard, gaming controls and local radio-frequency wireless networking. Kids can download and play games (alone or with friends up to 100 or so meters away), send instant messages and use the digital-assistant features to schedule activities.

All of this is designed to get users interacting. Cybiko's slogan is "stop playing with yourself." And its kind of wireless networked gaming is making its way to other personal digital assistants, like Palm and Windows Pocket PC devices. Cybiko also recently teamed up with Nortel Networks and Motorola to offer downloads of its games onto some Motorola phones. Indeed, video games are a major factor in motivating cell phone makers to add color screens and make other improvements in their displays, maintains Cybiko founder and CEO David Yang. There are other incentives as well—multimedia applications like surfing the Web and storing and sending photos. But, Yang says, "Games will be a big part of that, maybe more than 50 percent of all multimedia experiences." He also says that ad hoc local wireless networks of the sort formed by Cybiko handhelds could beat out mobile networks like Bluetooth and 802.11b for low-cost, low-power, short-range communications.

The Networked Home and Beyond

One of the most anticipated developments in the future of computing is the transformation of the game console from a stand-alone box hooked to the TV into the center of a revolution in home networking *(see "The Future of TV," TR November 2001)*. The latest game boxes bundle powerful processors, graphics and networking technologies in a stable and easy-to-use package, blurring the line between game machine and home computer. And as DVD capabilities are added in, these devices may spur the fabled convergence of different forms of media, from movies, TV and multiplayer games to the interactive Web. "You're seeing this compelling use of either immersive environments or novel user interfaces that are first developed in many single-user games," says Microsoft's Drucker. "Then you take the addition of multiple users, and you put that all together with the way the computers are starting to be used as communication devices and information-disseminating devices, and you're getting the new media."

By 2005, PlayStation chips will outpower Intel Pentiums and be poised to take control of home networks.

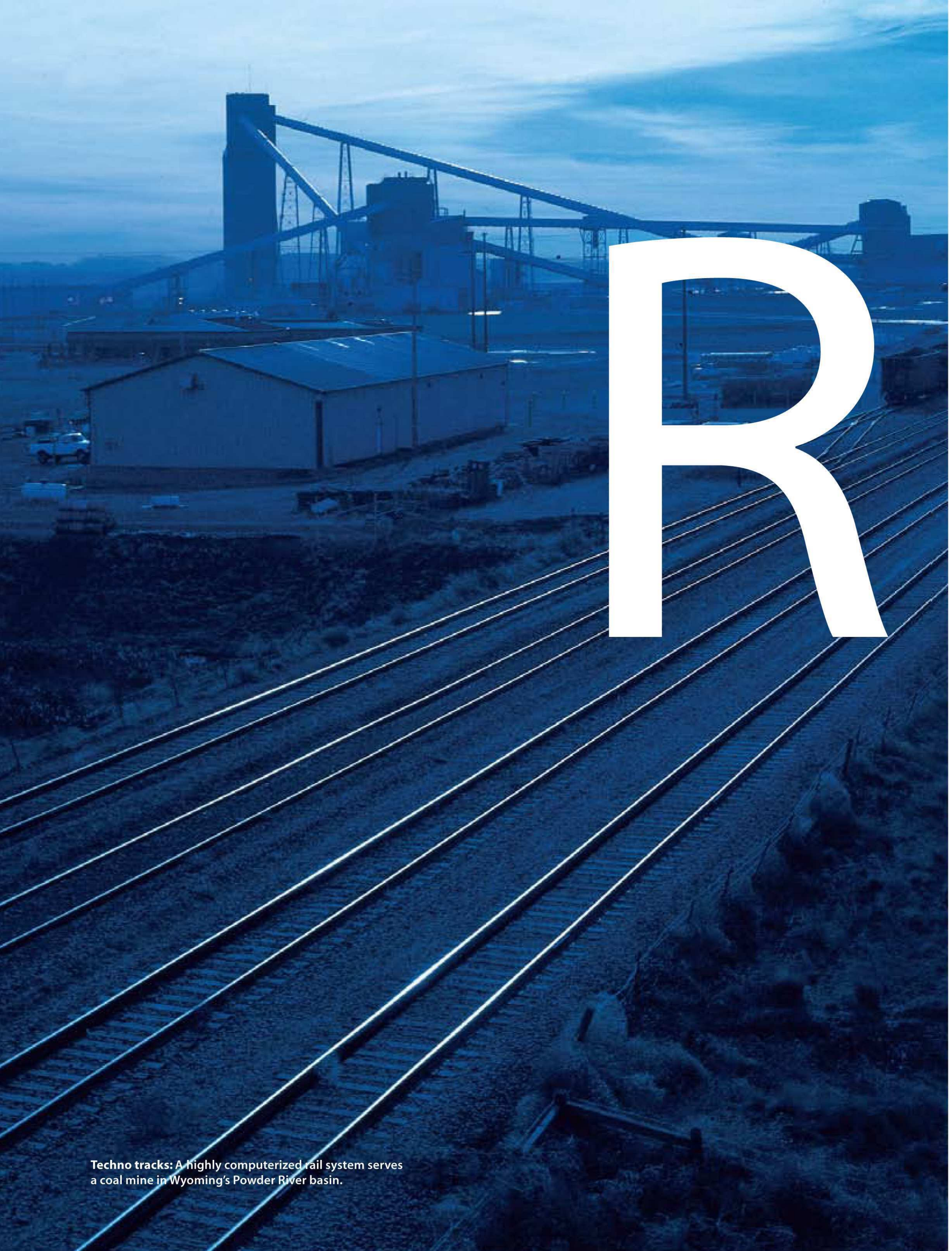
All this could be the first step toward controlling the home. Visionaries have long promised the day when a central computer controls all of a household's functions—from alarms and lights to washer-dryer and entertainment—making it possible, for example, to use the Web to turn off the coffeepot that was accidentally left on, or to identify a freezer component that's having trouble *before* it fails (and melts the ice cream). 3DO's Hawkins, for one, thinks that master computer might be the game box.

Hawkins calls the integrated DVD and networking features advanced by the PlayStation 2 when it was introduced in October 2000 "a watershed event" that could set the stage for the long-awaited household takeover. Even Microsoft, which maintains its commitment to the PC as the center of any home network, is preparing for this possible future—initially by giving the Xbox its own DVD and networking capabilities and, down the road, by expanding its involvement with other media. Sony in particular is fomenting the revolution, joining IBM and Toshiba to invest $400 million in developing a chip to power the PlayStation 3. Code-named Cell, it will process instructions in parallel, making it far faster and more powerful than today's serial processors. In fact, Sony estimates that by the third generation, around 2005, chips in this family will exceed the power of their Intel Pentium contemporaries—giving PlayStation consoles the ability to do much more than play games. In announcing Cell, Sony Computer Entertainment president Ken Kutaragi said it "will raise the curtain on a new era of high-speed, network-based computing."

This largely game-driven transformation of the home is a clear indicator of how gaming's influence has spread beyond traditional crossover areas like graphics into almost every aspect of computing. Nonetheless, many game developers don't view themselves as technologists at all. "There's a computer in the equation when a game designer is creating a game, but that doesn't have to be the focus," says gameLab's Zimmerman. "Creating a meaningful experience for players is not about technology."

That, he says, is because the heart of video gaming is something that can't be captured on a 500-million-transistor chip or in software: it's the experience a developer sets out to create for game players. Happily for the rest of us, though, developing games with the players' experience in mind often takes technology to its limits and provides new insights into what computers can do.

So let the games go on. TR



Techno tracks: A highly computerized rail system serves a coal mine in Wyoming's Powder River basin.

DIGITAL RAIL-ROAD

AN INJECTION OF COMPUTING POWER IS TURNING TRAINS INTO SMART MACHINES FOR PRECISELY CONTROLLED HAULING OF HEAVY LOADS.

By Don Phillips

Photographs by Brent Humphreys

No one had intended to make railroad history on May 5, 1998. It's just that there was a shortage of locomotives in Phippsburg, CO. Instead of the usual five locomotives, only four were available to pull a 108-car coal train up Union Pacific Railroad's steep Toponas grade on the western slope of the Rocky Mountains. What followed is, among locomotive builders, legendary.

The locomotives were brand new General Electric behemoths with a twist: their traction motors operated on alternating current rather than direct current. Climbing the Toponas grade that day, the trains slowed to a barely perceptible six meters per minute. No self-respecting engineer would have tried such a foolhardy trick with conventional direct-current motors: wheels would have slipped, the train would have stalled, and the motors themselves would have been fried like an egg. But none of those things happened. Indeed, later investigation showed that the locomotives had been producing more pulling power than was thought possible at that speed. This feat of strength initiated a radical transformation of railroading—a revolution that stems directly from advances in information technology.

Fill 'em up: Pulled by computer-controlled locomotives, coal cars slowly enter a silo in Wyoming's Black Thunder mine. **Right:** The trains' comings and goings are constantly monitored.

Technologically speaking, it is difficult to find anything in railroading that has not changed in the last decade. Dozens of microprocessors in today's diesel locomotives run almost all of their systems, from fuel feed to cab air conditioning. Pole lines that once flashed past the windows of speeding passenger trains are disappearing in favor of microwave or fiber-optic communications. Experimental new dispatching and control systems may soon tell engineers if they are using the most fuel-efficient throttle settings.

Say "trains" to most people and they think about the passenger variety. But in the United States, the railroads with the greatest economic impact are those that transport cargo. Railroads haul 25 percent of U.S. freight. They are easily the most efficient way to move coal, grain and bulk chemicals. But the railroad companies have long had a sort of love-hate relationship with cutting-edge technology. They only abandoned coal-fired steam locomotives, for example, when General Motors developed the diesel-electric engine and gave demonstrations to railroads around the country in the 1940s. And even then, many railroads stuck with steam for years.

However, over the last decade, railroads have been engaged in their own version of an information revolution. The combination of computers and wireless systems gives railroads greater customer service capacity and better dispatching and cost controls—as well as dispensing with armies of clerks. Charles Dettmann, executive vice president for operations, research and technology at the Washington, DC-based Association of American Railroads, argues that railroads' competitiveness—perhaps even their existence—depends on their use of information technologies.

"Railroad companies are a very hard sell. I am usually in the position of pushing them farther than they want to go," says Carl D. Martland, senior research associate at MIT's Center for Transportation Studies and a consultant to the railroad industry. "They insist on knowing there's going to be a productivity benefit and will only go as far as that benefit takes them. They have done a very good job of saying, 'Does this technology do me any good?'"

MODEL RAILROAD

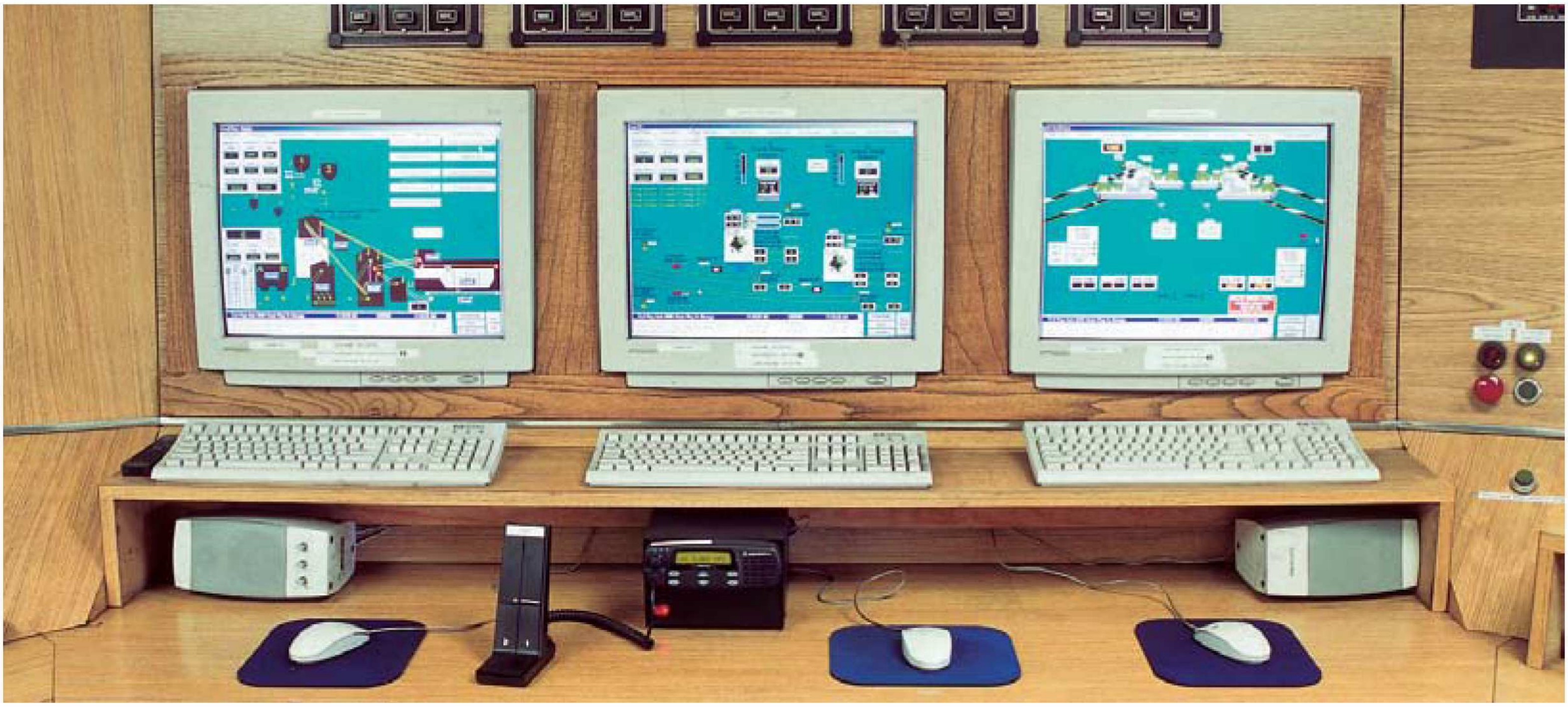
Just two decades ago, eastern Wyoming's Powder River basin was a barren, treeless outback with few people and no industry. But the region had something that as of the early 1990s the United States suddenly needed: lots of low-sulfur, relatively clean-burning coal. In fact, a thick seam of coal stretches under the eastern third of Wyoming. And the only practical way to move so much coal out of the remote Powder River basin is by rail.

The two railroads that serve the area—Union Pacific and Burlington Northern Santa Fe—have spent more than $5 billion to build the biggest, most modern industrial rail system in the country. Driven by tightening air pollution regulations, demand for low-sulfur coal is now booming beyond anyone's wildest dreams; one section of the line has become the first stretch of rail in history to support more than one billion kilograms a day.

And because the railroad and the mines are new, the Powder River operation provides a clean slate for the creation of the most efficient operation possible—without the burden of older infrastructure and the outdated technology that railroads have often kept running. Nowhere to be seen are the workers who once laboriously copied down all car numbers and faxed them to headquarters. As each empty train enters the mine, and as each loaded train leaves, scanners read automatic-identification tags, recording each car number and reporting the data to Union Pacific's Harriman Dispatching Center in Omaha, NE.

The Harriman Center is the heart of an ambitious effort to direct an entire railroad system from a central location—to dispatch trains using a computer program that chooses the points at which they meet or pass. The Harriman system controls traffic on more than 27,000 kilometers of Union Pacific track in 23 states—though human dispatchers can intervene at any time if they disagree with the computer's choices—and it allows for the coordination, days ahead of time, of movements over the entire railroad rather than on a single line or division.

Empty trains enter the Powder River basin's coal-containing silo under the railroad equivalent of cruise control. Trains creep in at around 1.5 kilometers per hour, speeds that only the most skillful engineer could match by hand. Computerized



loading chutes fill each car with the planned weight of coal—100,000 kilograms, accurate to within about .2 percent. A train can be filled with coal in 45 minutes, or about twice as fast as previous automatic loaders could manage.

As coal trains pull out of the Powder River fields, the locomotives constantly "talk" to Union Pacific headquarters in Omaha. The stream of data gives a running narrative of the train's condition, as reported by an array of sensors that monitor, for instance, the oil pressure, operating temperature, horsepower output and the rate of fuel usage. In the old days (say, the early 1990s), engineers knew that something was amiss with a locomotive only when it was already in serious trouble. That's when alarm bells would ring, or the engine would suddenly shut down or start smoking. Union Pacific is outfitting its entire fleet with onboard computers that constantly track the locomotives' location and health, then report this information to a maintenance desk at headquarters.

Once the fleet is equipped, a given locomotive will signal the Omaha center that it has a problem long before it tells the engineer. The sensors should usually catch problems hundreds or thousands of kilometers before they become severe enough for the engineer to care. Information that an engine is using 15 percent more fuel than normal, for instance, is of little concern to the engineer but of great interest to the maintenance technicians monitoring the locomotive.

Installing computers on locomotives is not exactly like putting them in the controlled environment of an office. Dirt, vibration and extremes of hot and cold are part of everyday railroad operation. Union Pacific experimented for months with various types of shock mountings and vibration-controlling material. According to chief technology officer Lyden Tennison, lessons were drawn from another enterprise that knows a thing or two about adapting high-tech equipment for inhospitable conditions. "We learned a lot from the military," he says. Locomotive technicians were at first amused, for instance, to learn that the military kept processors plugged into their sockets under constant vibration by tying them down with dental floss. Amused, but impressed: Union Pacific adopted this solution.

AC/DC

Throughout the diesel age, locomotives worked according to a simple principle: a diesel engine turned a generator that produced alternating electrical current, which was then converted to direct current to run the traction motors that drove the axles. The leap forward that made possible that pull up the Toponas grade depended on a fundamental shift in technology during the 1990s from DC motors to AC motors. This change has been enabled by the availability of fast, inexpensive microprocessors.

Power for both a DC locomotive and an AC locomotive starts its path to the wheels in the same way. In both types, a diesel engine turns a generator that produces AC power, which is then converted to DC. (The starting AC power, at a constant 60 cycles per second, could run the locomotive at only one speed.) Here, though, the technologies diverge. In a DC locomotive, the DC power goes directly to motors that turn the wheels. In an AC motor, the direct current passes through a series of computer-controlled components called inverters, which "chop" the DC power into AC power. This AC is in turn fed to the motors.

Computer chips make AC motors practical by regulating the flow of power with a precision impossible by any other means. The chips monitor and control the DC entering the inverters and make sure that they deliver the proper amount of AC to the traction motors. This is no small feat: each inverter may require as many as 500 on-off commands per second to regulate the AC flow. And while 500 commands per second may seem unimpressive in a day of gigahertz chips, the proper comparison is not with other computers but with human beings. Imagine a train engineer trying to make 500 changes in throttle position every second.

AC motors are more robust than their DC cousins. They've been put through brutal tests that demanded maximum possible power production, sometimes for days on end. Those tests went far beyond anything the worst railroad environment could produce, and the motors never came close to overheating, according to Michael E. Iden, Union Pacific's general director of car and locomotive engineering. As long as the equipment is operating properly, AC motors "really should never burn out," Iden says. Many railroads are even using AC locomotive power—instead of air

brakes—to hold trains stationary on heavy grades, Iden says. This technique, which avoids the time-consuming process of pumping off air brakes, would fry a DC motor in minutes.

Beyond their ability to pull heavier loads, AC motors improve overall efficiency. Each locomotive wheel makes contact with an area of rail no larger than a nickel. The percentage of weight on that wheel that is converted into pulling power is called "adhesion." While the best DC motors can muster an adhesion of about 30 percent, AC locomotives take advantage of precise computer control of the traction motors to achieve adhesion averaging 34 to 38 percent; each percentage point gain in adhesion provides the pulling power for five additional fully loaded coal cars.

MAKING TRACKS

Trains must run on tracks, of course. And once laid, the rail and ties must be maintained and inspected. Information technology is playing a transforming role in this traditionally labor-intensive affair. The last two or three years, for instance, have seen the advent of rail alignment systems that use lasers to gauge distance and direction. Computers then figure a track's correct curvature and angle of elevation and feed the information to machines that put the rail and ties into place. "The important thing is the ability to measure track geometry rapidly, without depending on human sight," says Louis Cerny, an independent railroad consultant in Gaithersburg, MD.

One particularly time-consuming rail maintenance job—spreading rock ballast between tracks—is also getting a shot of adrenaline. In June, Herzog Contracting—a railroad construction company based in St. Joseph, MO—delivered a new ballast train to Union Pacific. Unloading 60 cars of ballast normally takes at least two days; Herzog's train does the job in 30 minutes. As the train chugs along, computers guided by global positioning system satellites decide which car doors to open and how much ballast to pump out (even interrupting the flow at road crossings).

Similar advances are aiding track inspection. This job was once the domain of a lone trackwalker, carrying a few heavy tools, who walked along the track to see if it was shifting, or if spikes were pulling out or rail joints flexing too much. The ultimate in automated track inspection is a system delivered in 1999 to the Federal Railroad Administration by Plasser American, a maker of inspection cars, and Ensco, a manufacturer of railroad inspection hardware and software. This self-propelled mass of sensors and computers, rolling along at up to 145 kilometers per hour, generates readouts of track condition and dispatches crews to the locations of any problems. Most of the major freight railroads in the United States are either using such cars now or have ordered them.

Ensco has also developed remote monitoring systems that can be fitted to any railcar or locomotive. The systems, now in service for Amtrak and several commuter railroads, continually assess track anomalies, ride quality and a locomotive's mechanical health. When a problem appears, the monitors send an alarm via satellite or terrestrial wireless link. Detailed information on the problem and its exact location can then be accessed through the Internet. Other new inspection equipment uses computerized vision to look for defects in air brake hoses between cars. Pulsing lasers, fanning out in a pie-slice shape, can accurately produce an image of the wheel as it rolls—registering surface defects better than an experienced inspector can when the wheel is standing still. All of these detectors are designed to report trouble spots to the train crew or the dispatcher before a small problem grows and causes a wreck.

DOWN THE LINE

With the cost of technology constantly falling, railroads may be poised for another round of automation. The first candidate is an idea railroads have so far shunned called positive train control. The computers that control a locomotive's throttle and brake would be equipped with global positioning system receivers that tell them precisely where they are and how fast they're going. The modification was originally proposed as a safety enhancement, to prevent collisions: if an engineer sped past a stop signal, the system would signal the computer to slow or stop the train. That application failed to win over the railroads, though. "It would have cost a lot of money for a minimal safety improvement and so wasn't cost effective," explains MIT's Martland.

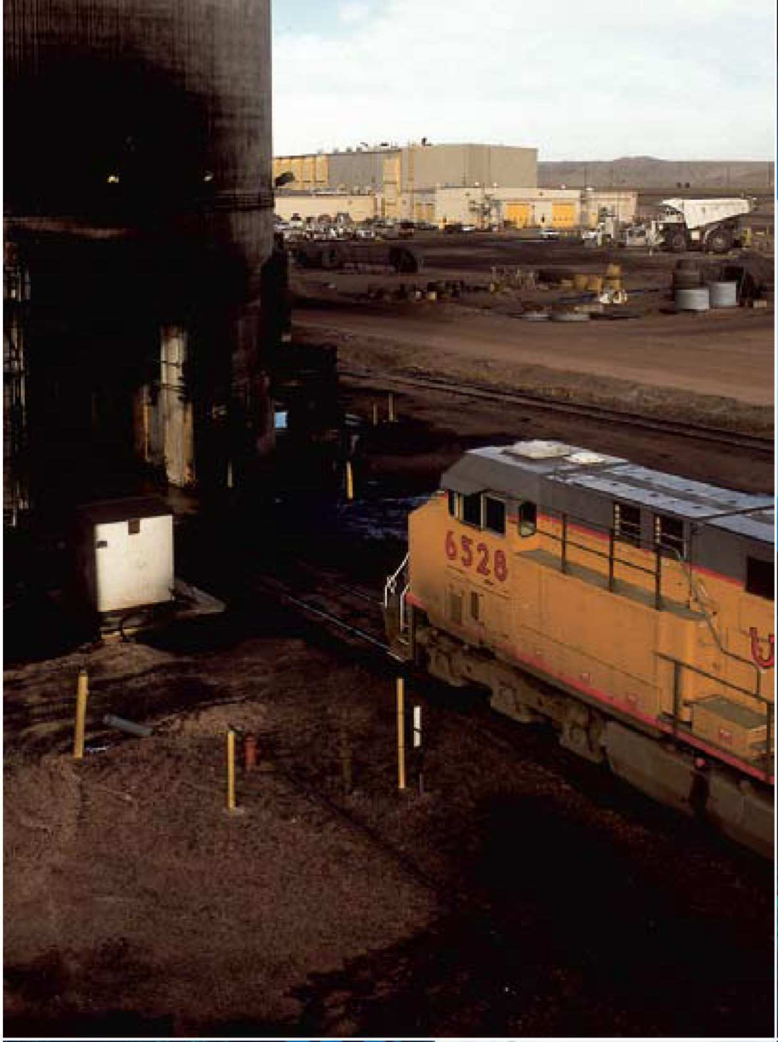
But many railroad officials are beginning to understand the business case for positive train control: the same technology provides continual updates on the location of every locomotive on the railroad. Advanced tracking and control technology is already in place on high-speed passenger trains such as those on the Boston to Washington line. The technology is also under development at a number of companies, most prominently Pittsburgh-based Union Switch and Signal.

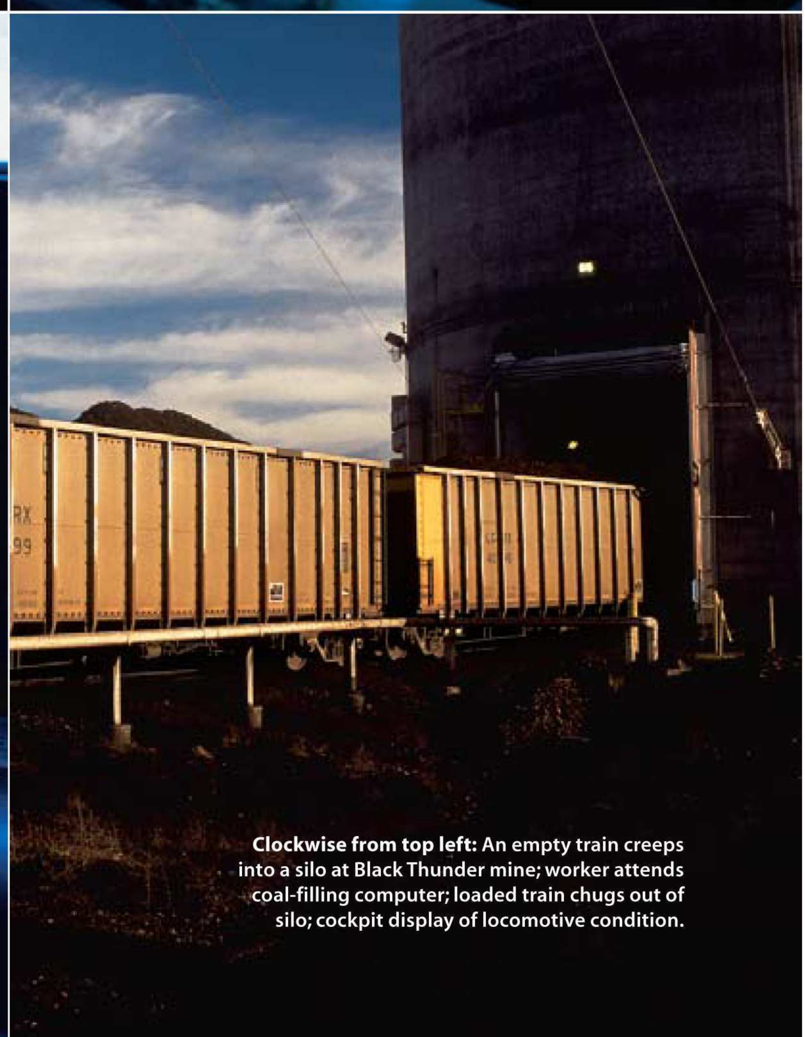
Combining satellites with computers to govern a train's speed is only one step toward completely computer-automated operation. Subways routinely operate this way; the driver goes along for the ride. But a freight train is not as simple as a subway. A long train may be climbing one grade and descending another at the same time, for example. And every freight train has its own braking characteristics, which an engineer must quickly master; mishandling a train can cause serious damage, like torn couplers and perhaps even derailments. Some railroads, however, are experimenting with computers that can learn a train's characteristics as fast as an engineer can. For example, computers have taken control of heavy ore trains in Minnesota, operating efficiently and stopping smoothly at red signals.

The next logical step is fully automatic operation, with an engineer on board only as a monitor. While the technology to implement this largely exists, other factors stand as barriers. The hefty up-front costs, for example, discourage railroads from installing new systems that don't provide an obvious bottom-line benefit. Safety is another concern; automated control systems must be proved extremely reliable before they can be trusted to replace human operators, and it is not until such a substitution is possible that the technology has much of an economic payback.

Computerization has already made it possible for railroads to operate with fewer people. The newest developments represent an assault on the jobs of the two most important people who run a train: the engineer and the conductor. And deployment requires renegotiating contracts with labor unions representing workers whom new systems might displace.

It is looking as if the long climb up the Toponas grade is just the beginning of an accelerating journey into a computer-automated future. Says Union Pacific's Iden, "We're just starting to tap into the benefits of technology." TR





Clockwise from top left: An empty train creeps into a silo at Black Thunder mine; worker attends coal-filling computer; loaded train chugs out of silo; cockpit display of locomotive condition.

AS HEAD OF A NEW CALIFORNIA STATE INSTITUTE, **SUPERCOMPUTER AND INTERNET PIONEER LARRY SMARR** WANTS TO USE THE WEB TO LINK TOGETHER EVERYTHING **FROM MEDICAL RECORDS TO TRAFFIC** TO THE ENVIRONMENT.

PHOTOGRAPHS BY SIAN KENNEDY

PLANET INTERNET

It would be hard to find anyone in information technology with the track record of Larry Smarr.

In 1985, he launched the National Center for Supercomputing Applications, a federally sponsored research facility, where he led the development of what would become today's Internet backbone. Years later he worked with a then unknown student, Marc Andreessen, to develop and commercialize the technology that would jump-start the Internet revolution: the Mosaic Web browser.

Now Smarr, perched in a seventh-floor office overlooking a eucalyptus grove on the University of California, San Diego, campus, directs the California Institute for Telecommunications and Information Technology. His is one of four state institutes set up last year to foster collaboration among government, industry and academe and spur advances in information technology, biotech, nanotechnology and the Internet—helping ensure California remains a high-tech powerhouse.

Throughout his illustrious career, Smarr, 52, has been a master facilitator, bringing people and institutions together to work on key technological challenges. At this new institute, he could face the greatest test to date of his consensus-building skills. Drawing upon the academic prowess of UC San Diego and UC Irvine, the center links three levels of government—state, federal and local—200 university faculty members, a slew of cutting-edge companies and the community at large to explore how next-generation Internet technologies will transform transportation, medicine and the environment. Freelance writer Eric Pfeifer braved T-shirt temperatures and calm skies to visit Smarr and hear his plans to spend $400 million in four years to create what he calls a massive "living laboratory."

TR: Okay, so what exactly is a massive "living laboratory?"

SMARR: Well, a number of S-curves will define the development of the Internet over the next five or ten years. Technology goes from a research phase to early adopters and then shoots up, so it seems like everyone is using it, and then it flattens out and becomes mature—a process which looks like a stylized letter *S*. This institute will be very critical in the first part of this curve—the research phase. We will discover things and fool around with them until they get to the stage where someone says, "Let's do a startup." So our goal is to weave together emerging technologies such as the wireless Internet, nanotechnology, chemical sensors and sensor nets, and digitally enabled genomic medicine. We are literally taking technologies and building them in the campus and the community. We will have a living laboratory of what it's like in the future today, three to five years before it becomes mass market.

TR: What's the primary benefit of bringing these all under one roof?

SMARR: If you have computer scientists and electrical engineers just studying technology, you may miss the big payoff for California and society—which is what will people do differently when the technology comes into being. How will our quality of life change? How will the economy of California change?

Take wireless technology. For 30 years we've been exponentially increasing the number of Internet addresses on the wired Internet. In the next three to five years, we will see more Internet wireless addresses come online than we created in the previous 30 years on the wired Internet. So for example, Hewlett-Packard donated 500 pocket PC devices—Jornadas—which will be equipped with wireless cards, so students will be able to access both local- and wide-area networks. So imagine that you have a pocket PC that you are taking notes on, and it has a wireless card, and I say, "Well, look at this." I give you a URL, and you pop it up and start working on it and walk out of the office. Well, as long as you are on this floor, you still have local access, but the minute you get in the elevator and head downstairs, your screen goes blank. With the integrated local-area and cellular network we are testing, once you're at the fringe of the local-area network, you will be able to pick up seamlessly onto the wide-area network.

You'll also have a map that will come up on your handheld, and when you're e-mailing your friend on campus, you'll be able to see literally that your friend is just behind the tree. So imagine crossing instant messaging with geography. With geolocation you have the opportunity for a meeting in physical space or a cyber-meeting. Right now, 500 first-year freshmen in computer science at UCSD have these Jornadas, and this will be increased next year. UC Irvine is also beginning experiments with some of their students.

TR: But in a "living laboratory," you don't know exactly how these students are going to use the new wireless technology.

SMARR: We don't want to know. We want to discover that. Let me give you an example. A decade ago, campuses all over the country dug up their quads and put in coaxial cable and then fiber to create what became the broadband networks inside the campus and between the campuses. We all thought this new network would enable supercomputing or virtual telescopes or something. What it enabled was Napster.

I can't tell you how many national meetings I was in over the last 15 years. Not once did anybody get up and say the reason we're building broadband networks on the campuses is to enable sharing of MP3s. So that was a discovered application of broadband networks that only could have come about when you had this very broad set of geographically separated students who had a common interest in listening to music. So that's what we want to do—let the kids figure it out. What's this good for? What are the new services?

TR: But it's not just students. Corporations also want some answers. It must be tough trying to balance the needs of corporate America with higher education.

SMARR: Yes, there is a lot of treacherous territory in finding the right balance between industry and academia, which have different sets of values and goals. We are really bringing a new kind of culture to academia. Now, the good news is that the 21st century is very much about this global virtual teaming. But the danger is the barriers will be too great to overcome.

Ultimately, we are trying to enable a crisper technology transfer. A lot of people on campus would love to be more involved with industry and entrepreneurial if they just knew how. And if you don't have the whole economic ecology

present, then students and professors feel like there's no natural way for them to do this on campus, so there's more of a tendency for the corporate guys to come in the dark of night and steal some of your best professors and students.

TR: What is government's role in all this?
SMARR: California governor Gray Davis put up $100 million for each of the four institutes. But he said you have to bring two dollars to the table for every one dollar I've given you. He told us that we could get the matching dollars by going after industry, going out to private individuals, or we could go to the federal government. And that's what we've done. Now, the majority of those dollars have been from industry because that's the shorter-term way to do it. Qualcomm says, here's an antenna, another company will say, here's a bunch of wireless devices, and HP will come in and say, here's Jornadas—which is why we can move very quickly. But at the national level you have to show how all 50 states will benefit. This means you have to go at a slower pace. At the moment, we have proposals which total about $100 million into the federal government, and we expect that to grow over time. These proposals cover a wide range of topics: quantum computing, materials research, sensor development, optical networks and biomedical imaging.

TR: You've worked with many emerging technologies. What characteristics do you think a new technology should possess if it is going to be commercially successful?
SMARR: I guess most of them have been standards based. If you go back to the Internet itself, it was TCP/IP based, and the national supercomputer centers were able to use that protocol to link themselves, and then the NSF [National Science Foundation] funded the regional centers and campuses and so forth. It could self-propagate. The Web was the same thing. Standards mean you can decentralize the build-out of a large-scale system; you don't have to do top-down management.

TR: Which technologies that you're working on are closest to commercialization?
SMARR: That's difficult to say. Probably 60 percent of my budget is for things that are going to happen in the next two to five years, for example optical networks or intelligent transportation. Thirty percent

of my budget is going to be on stuff that is five to ten years out, which is a lot of the smart sensors. Then 10 percent is for things that are really over the horizon, such as quantum computing and quantum communication.

TR: Let's start with what's coming down the line first—intelligent transportation.
SMARR: You've got this amazing thing today where a modern car has maybe 20 microprocessors and 60 sensors in it—none of which are connected to the Internet. We've got a hundred million vehicles. What if each of those cars had an Internet address? We'd know exactly where each car is and how fast it is going. If we have enough of these as tracer particles, then we have a good idea of the state of traffic as a whole. So you can begin to imagine your car telling you, "Don't go on the I-5, go up on I-15." You begin to imagine real-time traffic management.

Will Recker, director of UC Irvine's Institute of Transportation Studies, has worked with Toyota to get 50 cars. His plan is to have a pool of cars, all zero- or low-emission vehicles, at stations of rail lines, like the Amtrak Pacific Surfliner that stops in Irvine and San Diego. The idea is that a person gets off the train, walks up to the car, swipes a smart card, is authenticated and drives home. We will outfit the cars with GPS and other telematic sensors being designed in collaboration with UCSD. So these cars will be sampling the local traffic flow and wirelessly reporting back while the person is driving.

TR: What other smart sensors are you developing, and how will they ultimately be connected wirelessly to the Internet?
SMARR: If you look at a company like Nanogen, they are able to shrink a DNA array to about two millimeters square. What if you could take that and put it with system-on-a-chip technology so that you could integrate—on silicon—a microsensor along with embedded software, a large memory and an RF [radio frequency] or laser transmitter? And what if you could shrink that down to [two-thirds of a centimeter]? What that amounts to is a super sensor. It is not just detecting accelerations or biological and chemical signatures, but also doing vast amounts of computing.

We're doing a project with San Diego State University. They manage an ecological reserve in northeast San Diego County where the institute will be testing out these smart sensors. One of our other academic partners is the High-Performance Wireless Research and Education Network, an organization funded by the NSF that is building out a set of 45-megabit-per-second, point-to-point wireless Internet links across southern California using the unlicensed spectrum band. That's arguably 100 times faster bandwidth than any third-generation wireless cellular system you are going to see for five years. This network currently provides a wireless Internet infrastructure to this ecological reserve and sensors, which are measuring everything from atmospheric turbulence to the temperature of ground leaves to warn of potential brush fires. It also has sensors that are listening to bats to help animal behaviorists understand the bats' life cycle.

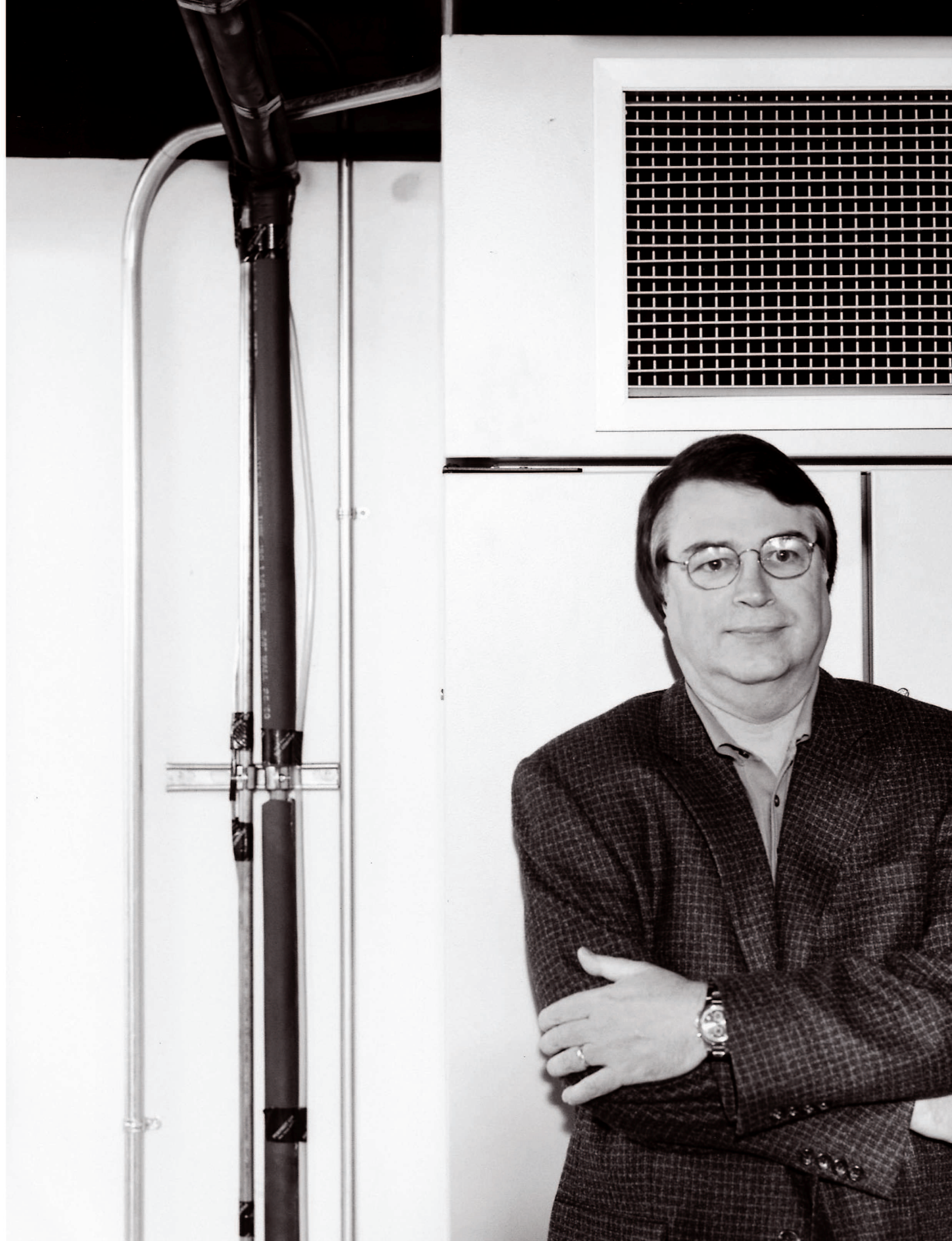
Eventually, at this ecological reserve and even across the country, there will be quality-of-water sensors that will monitor the major estuaries, and they will alert the appropriate officials if there is a pollution problem. That's one of our major goals: to establish an early-warning system for ecological damage. Gradually, bridges will have seismic sensors on them. Highways will have air quality monitors. We are going to have a society where there are sensors everywhere.

TR: This completely changes the physical nature of the Internet.
SMARR: Right now you could argue that humans are very much in the loop on the Internet. Over time, the percentage of traffic on the Internet that touches a human is going to be a very, very tiny fraction. More and more, it will be traffic between computers, between sensors and databases, between embedded processors like in cars or PDAs [personal digital assistants]. The upside to this is we are going to have a much more automated society; we are going to have a world of intelligent agents that go off and work for us during the day or night. Everyone is going to have dozens of personal servants that are software.

TR: How about genomic medicine. Where does it fit into this mix?
SMARR: We are just now getting going on digitally enabled genomic medicine. One of our professors at UCSD just got a $25 million National Institutes of Health grant to set up what's called BIRN, the Biomedical Informatics Research Network. This will be a national network, initially for brain imaging, involving Harvard, Duke, Caltech, UCLA and UCSD. Right now, there is no central place where all MRIs are stored. UCSD will be the software and network developer for this national repository. People studying genetics will be able to do 3-D visualization. They will be able to fly their way inside of a particular brain, and then by software, we will link portions of the brain to genetic and proteomic databases. So someone flying through a brain will be able to click on the pituitary gland, and up will come those genes that are expressed in the release of its hormones. The beauty of this is that we aren't doing brain research, we are building an infrastructure into which knowledge can be poured. If this works, and we think it will, then the NIH wants to extend it to other organs and many other laboratories.

TR: You've hit two home runs: developing the Web browser and the Internet backbone. Do you think you'll be able to hit your third one here at the institute?
SMARR: [Laughs.] In each of those cases I helped to catalyze things. I was a midwife as opposed to a father or mother. The best I can do is get a bunch of smart, innovative people together and let them live in the future. The chances are pretty good they will discover new features or services about the infrastructure that will get widely adopted. What I'm trying to do, what I've always tried to do, is accelerate the future getting here.

"OUR GOAL IS TO WEAVE TOGETHER **EMERGING TECHNOLOGIES** SUCH AS THE WIRELESS INTERNET, NANOTECHNOLOGY, CHEMICAL SENSORS AND DIGITAL MEDICINE AND **BUILD THEM INTO THE CAMPUS** AND THE COMMUNITY."



INTELLECTUAL-PROPERTY ECOLOGY

What do bird watchers and bird hunters have in common? The question was posed by Duke University law professor James Boyle, one of the hosts of an extraordinary meeting on intellectual property held last November at the Duke Law School in Durham, NC. Boyle's answer is provocative: after years of pursuing separate agendas, these incongruous groups ultimately came to understand that they have a shared interest in protecting the "environment."

Does the same principle hold in the intellectual-property realm? Do we all, no matter what our fields of endeavor, need to cultivate a greater appreciation for the IP equivalent of the natural environment? Judging from the energy and commonality at the Duke meeting—billed as the first-ever "Conference on the Public Domain"—it would appear that we do.

Let's consider this environmental analogy. As recently as the 1960s, there was no "environment" in the broad sense of the word. Sure, some conservation groups like the Sierra Club had long been in the wilderness protection business. And Rachel Carson's landmark *Silent Spring,* published in 1962, brought the misuse of pesticides to public attention. But still, even with rallying points like the Cuyahoga River catching fire in Cleveland in 1969, the people who worried about such things tended to see them as *disparate* issues. Like water pollution. Or overpopulation. It wasn't until 1970 that such groups finally came together at the first "Earth Day."

Now, fast-forward a few decades and jump into that intangible, amorphous realm we call "intellectual property." There is a growing catalogue of worries about IP issues—from the emergence of overly broad "business method" patents to heated charges that proprietary claims on pharmaceuticals stifle affordable access to medicine in the Third World. A day hardly goes by without a high-profile intellectual-property battle heading to court. Meanwhile, university researchers are griping that open, collegial dialogue is being eroded by proprietary interests and secrecy as professors vie to create startups and get rich.

These issues are interwoven because they all involve balancing similar kinds of private and public needs in a knowledge-based economy. And yet, the various parties—from the League for Programming Freedom to the American Library Association—have tended to work in isolation on their own narrow sets of issues. But the parochialism is fading as parties learn they're arguing about the same issues. Which is why the Duke meeting could go down as a watershed: it marked the start of an organized movement to protect the conceptual commons.

In attendance were an eclectic array of actors from distinct intellectual-property battles. Members of the open-source software movement were there in force, as were first-amendment and copyright lawyers fresh from some big recent court cases (like Napster and that absurd battle in which author Alice Randall finally won the right to publish *The Wind Done Gone,* her parody of Margaret Mitchell's *Gone with the Wind,* despite shrill objections from the Mitchell Trust.)

Academic scientists were also well represented. Several groups are banding together to insist on licensing arrangements that will mandate that, six months after publication in a scientific journal, articles will be made freely accessible to all over the Web. Similarly, biomedical experts came to explore ways to surmount barriers that prevent exchange among colleagues—things like the almost notorious material transfer agreements that include increasingly stringent provisions about how research materials and results can be shared. Equally notable was the presence of compilation artists whose work—deriving from "sampling" pieces of existing art and music—has been shut down or forced underground by strict new restrictions on copying like the Digital Millennium Copyright Act.

It was fascinating to see the sparks of commonality among this diverse group. Warning that greed and shortsightedness threaten to despoil innovation the way a previous frontier-minded generation despoiled the natural environment, a series of speakers urged the group to consider itself as an environmental movement for the new millennium—guarding collectively against the encroachment of proprietary intellectual-property rights.

A broad conception of "the environment" galvanized a sea change in perceptions about the use of natural resources. Can a similar "environmental" movement blossom in intellectual property?

The environmental theme is powerful indeed. A growing body of thinkers now believes society should view the sphere of information and ideas we call the "public domain" as an ecosystem. As such, it can remain healthy only if its relationship with the market—as embodied in intellectual-property law, technology and social practice—is kept in balance.

There's little question that, once it caught on back in the 1970s, a broad conception of "the environment" helped galvanize a sea change in perceptions about the appropriate use of natural resources. It is too early to know the extent to which the disparate critics of the current IP regime will coalesce under a similar banner. Still, an important conceptual hurdle has been overcome. And ultimately, maybe even the IP bird hunters and bird watchers can find common ground, providing financial incentives for people to innovate by protecting the fruits of their labor, but also supporting enough sustainable cross-pollination to spur future innovation. TR

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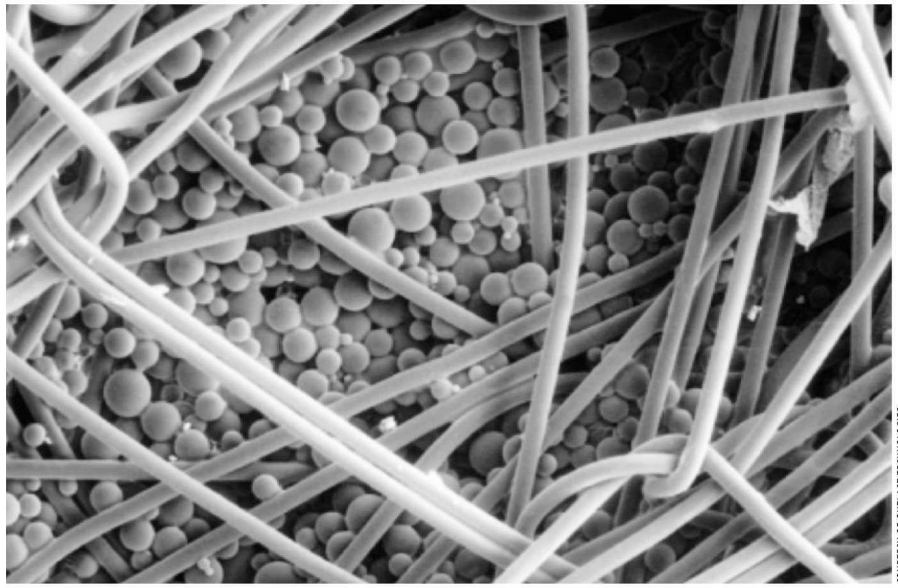


COURTESY OF OUTLAST TECHNOLOGIES

By Tracy Staedter | Illustration by John MacNeill

PHASE CHANGE MATERIAL

Microcapsules that keep you comfy

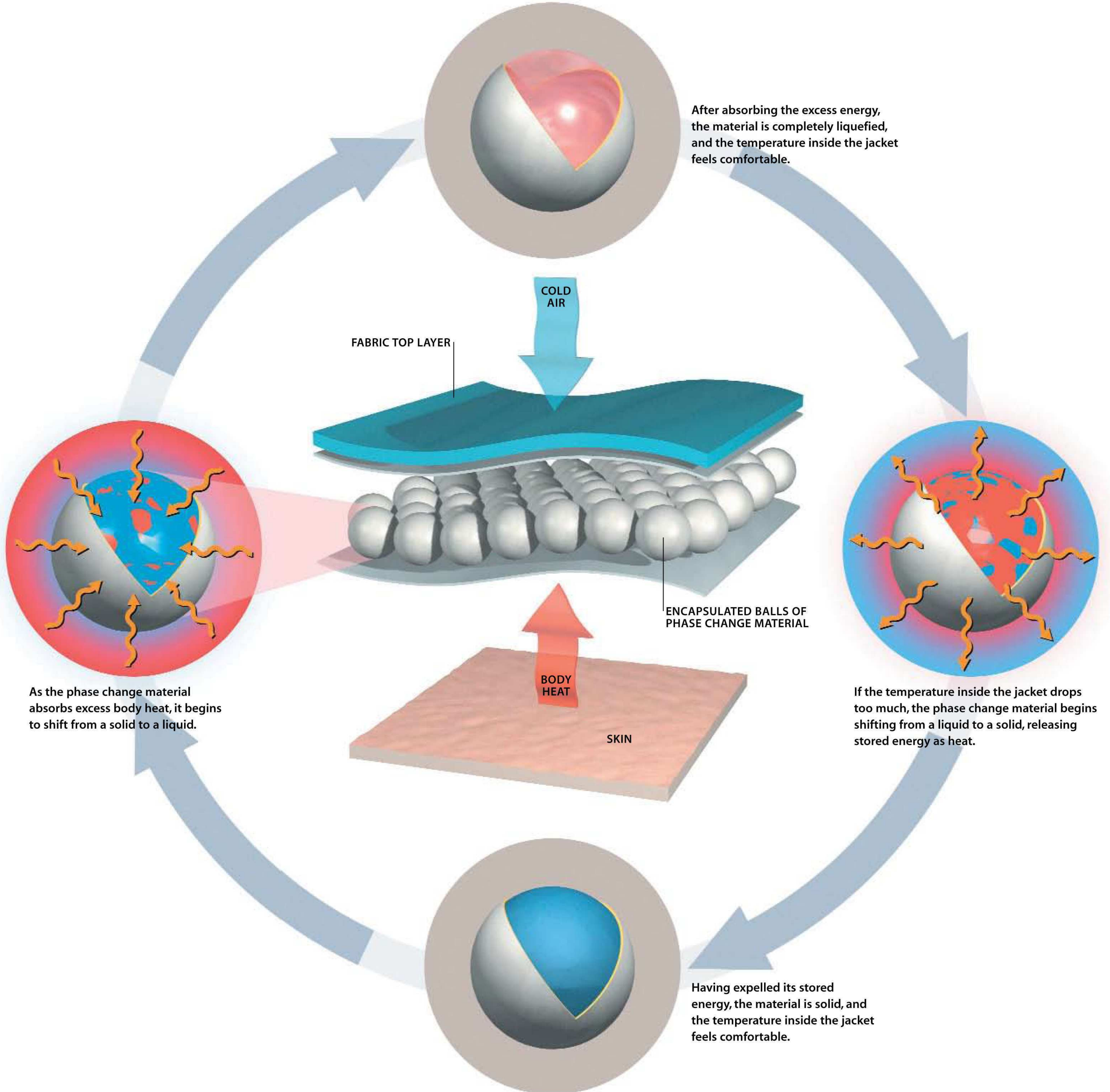
Winter presents an interesting apparel challenge for those who want to play outside. Wear too many layers and you'll sweat; wear too little and you'll freeze your fanny. Lately, technology has offered up a solution: a paraffin-wax-like substance known as phase change material encapsulated in microscopic balls of heat-resistant plastic similar to that used in dishwasher-safe dinnerware. Coated onto fabrics, the phase change material melts and freezes before you do and, in the process, stores and expels heat energy. Clothing can now be engineered to respond to your body temperature—and heat up or cool down to keep you feeling just right.

Phase change materials work because they are designed to maintain the midpoint of a narrow temperature range. One phase change material used in fleece jackets, for example, stays between about 27 °C and 38 °C when worn—or around 32 °C, which feels comfortable next to the skin. The specific range is determined by the lengths of the hydrocarbon molecules that make up the material; in different proportions they specify different ranges.

When a skier puts on the jacket, some of the phase change particles absorb body warmth and partially melt. During a strenuous run down the mountain, the skier's body generates excess heat, which melts the remaining microcapsules. Because the heat is absorbed by the melting material rather than reflected back toward the body, the temperature inside the garment stays comfortable. On the chairlift ride back up the mountain, the skier cools down. But as the temperature between the jacket and the body drops, the microcapsules refreeze—in the process releasing their stored heat. The phase change material can run through these thermal cycles indefinitely, easily outlasting the life expectancy of the garment.

Two companies specialize in this material: Frisby Technologies in Winston-Salem, NC, and Outlast Technologies in Boulder, CO. By early 2003, just about every major brand of outdoor apparel will offer a line of clothing made with phase change materials, turning more fair-weather fans toward cold winter fun. TR

For an animated version of this illustration, go to www.technologyreview.com/visualize



BLOG THIS

A few months ago, I was at the Camden Pop!Tech conference, and the guy sitting next to me was typing incessantly into his wireless laptop, making notes on the speakers, finding relevant links and then hitting the send key—instantly updating his Web site. No sooner did he do so than he would get responses back from readers around the country. He was a blogger.

Bloggers are turning the hunting and gathering, sampling and critiquing the rest of us do online into an extreme sport. We surf the Web; these guys snowboard it. Bloggers are the minutemen of the digital revolution.

"Blog" is short for "Web log." Several years ago, heavy Web surfers began creating logs—compendia of curious information and interesting links they encountered in their travels through cyberspace. Improvements in Web design tools have made it easier for beginners to create their own Web logs and update them as often as they wish—even every five minutes, as this guy was doing. Blogs are thus more dynamic than older-style home pages, more permanent than posts to a Net discussion list. They are more private and personal than traditional journalism, more public than diaries.

Blogger.com, one of several sites at the heart of this phenomenon, now lists more than 375,000 registered users, adding 1,300 more each day. Users range broadly—from churches that have found blogging an effective tool for tending to their congregations' spiritual needs to activists who see blogging as a means of fostering political awareness, and fans who use blogs to interact with other enthusiasts. Most often, bloggers recount everyday experiences, flag interesting stories from online publications and exchange advice on familiar problems. Their sites go by colorful names like Objectionable Content, the Adventures of the AccordionGuy in the 21st Century, or Eurotrash, which might leave you thinking that these are simply a bunch of obsessed adolescents with too much time and bandwidth.

Yet something more important may be afoot. At a time when many dot coms have failed, blogging is on the rise. We're in a lull between waves of commercialization in digital media, and bloggers are seizing the moment, potentially increasing cultural diversity and lowering barriers to cultural participation.

What will happen to democracy in the current media environment, where power is concentrated in the hands of a few publishers and networks? Media scholar Robert McChesney warns that the range of voices in policy debates will become constrained. The University of Chicago Law School's Cass Sunstein worries that fragmentation of the Web is apt to result in the loss of the shared values and common culture that democracy requires. As consumers, we experience these dual tensions: turn on the TV and it feels like the same programs are on all the channels; turn to the Web and it's impossible to distinguish the good stuff from the noise. Bloggers respond to both extremes, expanding the range of perspectives and, if they're clever, creating order from the informational chaos.

At the risk of egotism on my part, let's imagine what happens when bloggers get hold of the online version of "Digital Renaissance." Some may post links to the column calling me a pretentious ass. Others, if I am lucky, may feel that I have some interesting insights. My arguments for grass-roots media may be taken up by conservative and progressive sites alike but framed differently depending on the bloggers' own ideological agendas. Once this column appears, my authorial control ends and theirs begins. As these words move through various contexts, they assume new associations and face direct challenges, but they also gain broader circulation.

Ultimately, our media future could depend on the kind of uneasy truce that gets brokered between commercial media and these grass-roots intermediaries. Imagine a world where there are two kinds of media power: one comes through media concentration, where any message gains authority simply by being broadcast on network television; the other comes through grass-roots intermediaries, where a message gains visibility only if it is deemed relevant to a loose network of diverse publics. Broadcasting will place issues on the national agenda and define core values; bloggers will reframe those issues for different publics and ensure that everyone has a chance to be heard.

We're in a lull between waves of digital-media commercialization, and bloggers are seizing the moment—potentially increasing cultural diversity and lowering barriers to cultural participation.

It may seem strange to imagine the blogging community as a force that will shape the information environment almost as powerfully as corporate media. We learn in the history books about Samuel Morse's invention of the telegraph but not about the thousands of operators who shaped the circulation of messages, about Thomas Paine's *Common Sense* but less about the "committees of correspondence" through which citizens copied and redistributed letters across the colonies, about the publication of Harriet Beecher Stowe's abolitionist blockbuster *Uncle Tom's Cabin* but not about the teenagers who used toy printing presses to publish nationally circulated newsletters debating the pros and cons of slavery. In practice, the evolution of most media has been shaped through the interactions between the distributed power of grass-roots participatory media and the concentrated power of corporate/governmental media.

As the digital revolution enters a new phase, one based on diminished expectations and dwindling corporate investment, grass-roots intermediaries may have a moment to redefine the public perception of new media and to expand their influence.

So blog this, please. TR

THE DIGITAL DIVIDEND

Bridging the digital divide will pay off for business *and* government. BY STUART N. BROTMAN

Political, intellectual and business leaders are engaged today in a vigorous and far-ranging debate over what should be done to address the "digital divide"—the fact that various geographic, socioeconomic and cultural subpopulations have widely varying access to a range of digital technologies, including computers, the Internet, mobile phones and, increasingly, TV. These conversations encompass multiple perspectives and options—everything from giving schools, community organizations and citizens of lesser-developed countries broader access to computers and the Internet to simply letting market forces run their course. And they are truly global, whether in various meetings of the United Nations or as a prominent agenda item at the annual G8 summit of the world's leading industrial countries. Yet strikingly, they lack a single organizing principle.

The Luddites, for example, argue that no digital divide exists because technology doesn't really organize anything. The Technologists believe that with a few government policy tweaks, hardware and software dispersion through the marketplace will address any gaps. The Market Adherents say that market forces will eliminate the divide without any government involvement. Meanwhile, the Digital Egalitarians want to mandate equal access to technological tools throughout all strata of society, the Digital Democrats seek a political order that enables all people to participate as e-citizens in a cyberdemocracy, and the Globalists view the divide as proof that the United States is digitally isolating itself from the rest of the global economy. In short, there are many perspectives, but no encompassing view.

None of these characterizations captures the full extent of the digital divide, which in fact comprises many fissures rather than a single fault line. Yet the most significant divide today—one that will bear upon the way all the others play out—may be that between policymakers and the business community.

GENE GREIF

The digital divide is not only about offering Internet access to every citizen, nor is it only about social policy or computer penetration. The stakes are in fact much greater. Creating what I call the "digital dividend" will enable businesses to thrive at a new level of post-industrial innovation. The digital dividend is the set of outcomes that the private sector can achieve by promoting widespread penetration and use of digital technologies. Within companies, this can translate into better-trained, more productive employees; outside, it can lead to expanded sales and marketing opportunities at home and abroad, as well as a more diverse supply chain.

Government has taken the first steps in identifying and addressing aspects of the digital divide. Yet government cannot and should not be expected to lead on this issue. Instead, the business community must take on that role.

Government initiatives are insufficient for several reasons. First, many innovations are fundamentally driven by the marketplace—and government can't dictate the market. Second, with budget surpluses turning into deficits, policymakers today have fewer resources with which to close the fissures.

Given these factors, and more importantly, because of the tremendous stakes for the private sector, business leaders must engage with the policy community to develop strategies for spreading digital technologies.

Businesses today are uniquely poised to realize the benefits of this effort. Today's technologists are pursuing a "digital manifest destiny" featuring robust networks connected by wires, cables and the ether. Satellite and wireless communications, content digitization, broadband network access via cable or telephone lines, and many other technologies are inexorably converging. The result of such connectivity is a web of networks, each of which becomes exponentially more powerful as it grows. The business community must make this happen better, faster and in ways that help business.

For example, within corporations, managers must make sure lower-skilled workers get the training they need to participate in new forms of work. The digital-proficiency gap between high- and low-skilled employees must be closed. Mobile and work-at-home personnel also need an adequate technological infrastructure to link them to company systems, customers and coworkers.

The digital dividend will not only bring greater access to computers and the Internet; it will enable businesses to thrive at a new level of postindustrial innovation.

Beyond the office walls, the private sector must also help to prepare tomorrow's work force. U.S. workers will slip further behind their competitors abroad unless the educational system gets corporate help to prepare students to work in the digital economy.

The emergence of the electronic marketplace as the hub of domestic and global commerce creates another compelling argument for business to help close the digital divide. As trade occurs today on an increasingly global stage, there are numerous opportunities to develop relationships with suppliers in Bombay as well as in Boston. Additionally, the spread of digital technologies offers an opportunity to meet new consumer demand and to create more sophisticated customers for products and services.

In order to realize the digital dividend, the business community must form a new compact with the policy world. Policymakers have long promoted the concept of "universal service" to ensure that income and geography are not insurmountable barriers to telecommunications access. The business community recognizes the economic efficiency of having as many people connected as possible, but it looks to the bottom line rather than social policy as the rationale for supporting network expansion. Joining these two principles can generate exponential growth in digital-technology penetration by virtue of both government support and private investment.

Let's focus on these two principles in further detail. In the United States, universal service—the idea of extending the telephone network to all—was the brainchild of Theodore Vail, chairman of AT&T from 1907 to 1919. Vail believed a private-/public-sector compact was the most effective mechanism for realizing his ambitious goal, and he prevailed upon the government to grant AT&T a regulated monopoly in exchange for building out the telephone network. Vail's idea was to make a ubiquitous telephone network into a source of both private profit and public good.

The insights of Ethernet inventor [and *TR* board member—ed.] Bob Metcalfe are equally compelling. "Metcalfe's Law" states that the value of a network increases exponentially as it grows. Such a law applies geometrically to the digital dividend, which encompasses not one network but many. But in order to achieve the promise of Metcalfe's Law, it will not be enough to stand by as government develops targeted subsidy programs and technology drives prices down to more affordable levels—processes that will require considerable time.

Combining Vail's wisdom with Metcalfe's insight offers a better base for promoting government support and private investment simultaneously. And it can be done without creating any monopolies. For example, if businesses agreed to underwrite access to digital networks and devices for far larger populations, government could provide appropriate tax incentives in support. This emphasis on a digital dividend can generate obvious payoffs for both the private and public sectors.

At the 2001 G8 summit in Genoa, Italy, President George W. Bush and other heads of state approved an action plan for seeking private-sector involvement in improving connectivity, lowering costs, establishing national Internet strategies, deploying information technology in health care and development aid, and fostering entrepreneurship. But if this plan is to be realized, policymakers in each nation will have to consult closely with the multinational business community, which is starting to realize how the spread of digital technologies can expand its markets. One vital first step is to ensure that there is a pro-competitive regulatory framework in place so that business can calibrate strategies for investing and achieving profits.

Between now and the June 2002 G8 summit in Canada, the leaders who met in Genoa must bring together social-policy and business policy interests to address this critical issue. Linking the digital divide and the digital dividend is something that Luddites, technologists, egalitarians, globalists and free-market adherents need to agree upon if we are to achieve real-world results both in the United States and abroad. TR

Stuart N. Brotman (sbrotman@brotman.com) is the author of Creating the Digital Dividend: How Business Benefits by Closing the Digital Divide *(Harvard Business School Press). The book is scheduled for publication in late 2002.*

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PEOPLE AND ORGANIZATIONS MENTIONED IN THIS ISSUE

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VIDEO GAME ODYSSEY

The long journey from brown box to Xbox

In the United States, people spend about as much money on home video games as they spend going to the movies. And the multibillion-dollar industry shows little sign of slowing down: Microsoft's Xbox, released last November, shipped more than a million units in less than a month. But the first home video game system, Magnavox's Odyssey, took over 20 years just to get off the ground.

Around 1951, Loral Electronics engineer Ralph H. Baer had a novel idea: a TV on which a viewer could also play games. His bosses at the time nixed the concept, but in 1966, after a move to military contractor Sanders Associates, Baer wrote a proposal entitled "Conceptual, TV Gaming Display." In it, Baer envisioned a game system, compatible with any television, on which viewers armed with simple controllers could play sports, strategy and target-shooting games. This time his bosses let him assign a few technicians to the development of the idea.

A prototype system was nicknamed "the brown box." Its graphics were amazingly primitive by today's standards—white dots on a black screen—and players had to put plastic overlays on the TV screen to create the virtual tennis courts, shooting galleries and racetracks under which the white dots flickered. However, Magnavox took a chance and licensed the system, releasing it in 1972 as the Odyssey *(above)*. Although the device sold about 100,000 units in its first year, stores didn't really know how to market it effectively; many consumers thought the Odyssey would work only with Magnavox TVs, and sales quickly declined. But fledgling game company Atari, whose hit 1972 arcade game Pong was inspired by the Odyssey's Ping-Pong game, saw the potential of a home gaming system and soon released its own household version of Pong. The company unleashed the 2600 Video Computer System in 1977—and home video games began their takeover of America's living rooms.

Magnavox tried unsuccessfully to keep up by releasing the ill-fated Odyssey^2 in 1978. In the long run, though, the initial home video game patents proved winners: between licensing deals and various legal actions, other game makers, including Atari, Nintendo and Sega, were forced to cough up nearly $100 million to Sanders and Magnavox. Baer, now an independent inventor, went on to create, among other diversions, Milton Bradley's popular electronic pattern-matching game Simon. What's ahead for home video game technology? Baer sees interactive Web-based video games as the next big thing. "I think the future is already here," says Baer. TR

COURTESY OF RALPH H. BAER

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